DOMESTIC PRODUCTION ISSUES IN CHROMIUM AND PLATINUM-GROUP METALS

THESIS

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THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Contract Management

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September, 1988

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Preface

I would like to thank my faculty advisor, Dr. William Pursch, whose guidance and straightforwardness helped me to accomplish this project. I am also indebted to those individuals in government agencies and private organizations who shared their expertise and printed information with me. Most of all, I wish to thank my wife Anna, and my daughters Cocav and Rikki for being patient with me while I worked through this research process.

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Abstract

The purpose of this study was to: 1) identify the domestic resources of chromium (Cr) and platinum-group metals (PGM), 2) identify the federal environmental statutes and federal agencies affecting domestic production of Cr and PGM, and 3) to find the relationship between the federal environmental statutes and the development of domestic Cr and PGM mines.

Using an extensive literature search, interviews, and a case study, this study found that there are large resources of Cr and PGM in this country but much of them remain subeconomic to develop. Many wilderness areas have not been thoroughly explored for Cr and PGM, especially in Alaska where infrastructure problems would make mining very expensive in some remote areas.

Getting permission to develop mining projects or even to explore wilderness areas can be difficult if not impossible, in some cases, because of environmental statutes and programs that have been implemented to stem the increasing volume of pollutants being dumped in to the air, water, and soil. The environmental programs are being implemented in such a way that the state and local governments have a significant voice in decisions made about mining projects.

The Stillwater mining project is an example of how a venture can work through the current system of environmental laws, fulfill its obligations to clean up after itself, and still operate successfully providing strategic minerals to the nation's defense and commercial industries.

DOMESTIC PRODUCTION ISSUES IN CHROMIUM AND PLATINUM-GROUP-METALS

I. Introduction

General Issue

The United States relies heavily on imports of some two dozen metallic minerals for its defense and industrial needs. Reasons for importing these minerals usually involve some combination of abundant overseas supplies, international market price levels, and dwindling domestic supplies. Domestic mines and smelters are closing down in significant numbers and are unable to fill, in some cases, even minor portions of industrial demands for these metallic minerals. Several of the imported metals (e.g., chromium, cobalt, manganese, platinum-group metals) are critical to the defense industry for everything from jet engines to electronic components. The U.S. imports 90 to 100% of its requirements for some of the above two dozen minerals. Much of the import requirement is filled by potentially unstable sources for the U.S. (e.g., South Africa and the U.S.S.R.).

Specific Problem

The domestic metallic minerals industry is plagued with political difficulties, resource availability problems, and international competition. One problem (of many) that is hampering the U.S. mining and smelting industry is the expense of complying with federal environmental statutes and regulations. The U.S. government has taken a "hands off" approach to helping this industry after levying burdensome pollution reduction requirements (billions of dollars worth) on it (54:52; 6:44). Allowing the mines and smelters to shut down increases U.S. vulnerability to international market upheavals and shortages.

The enactment of environmental protection laws represents a huge and legitimate interest group from all levels of society that lawmakers cannot ignore. The environment is no longer free for industrial consumption but rather a resource that the public owns and has a vested interest in (32:495). The protection of air, water, and soil is not a "fad" issue and will remain a concern to be reckoned with in the future. The problem is that while the U.S. government policy of allowing mines and smelters to go out of business in some part addresses the issue of environment, it ignores a national security problem of considerable importance.

Definitions

Strategic Minerals. From the U.S. Geological Survey's International Strategic Minerals Inventory Summary Report:

> The term "strategic minerals" is imprecise. It generally refers to mineral ore and derivative products that come largely or entirely

from foreign sources, that are difficult to replace, and that are important to a nation's economy, in particular to its defense industry. Usually the term implies a nation's perception of vulnerability to supply disruptions and of a need to safeguard its industries from the repercussions of a loss of supplies [53:1].

Reserves. A term to include *in-situ* minerals that can be *economically* extracted at the time of interest; i.e. large changes in market prices over time can change reserve quantities.

Reserve Base. Includes a larger quantity than reserves. Encompasses economic resources (reserves), as well as marginally economic and subeconomic resources that are projected to become economic in the future through technology and/or market changes.

Resources. The largest category that can include all potential *in-situ* minerals that are estimated to be potentially economical either now or in the future. Resource estimates can include not only known or measured resources but undiscovered resources that are inferred rather than identified (5:184).

Background

The U.S. had difficulties filling demands for strategic materials during both world wars and the Korean conflict (38:15). The U.S. Congress has been dealing with the issue of strategic minerals for a number of years. It has taken recent legislative steps to address the related problems of national security and the declining domestic minerals industry. There are questions from industry as to how well the congress has watched over the implementation of these programs (54:52). The following chapter will look at the geologic and geographic disposition of chromium and platinum-group metals (PGM), as well as industry and government problem assessments.

Methodology

Investigative Questions. 1) What resources of PGM and chromium does the U.S. actually have?

2) What are the current federal environmental statutes affecting this industry?

3) What is the relationship between the federal environmental statutes and platinum-group metals and chromium mining development?

Scope of Research. This study will focus on two critical metallic minerals: chromium and the platinum-group metals. The difficulties of obtaining reliable domestic sources of mining and smelting for these two will be discussed. Other mineral mining and smelting processes will not be dealt with except where either of these two are obtained as a by-product of another mineral. Also excluded as foci of this study are the National Defense Stockpile, material replacement technologies, and breakouts of specific material applications in military hardware.

Particular Method. The major investigative approaches to this rather exploratory problem were a variety of literature searches and compilation followed by government and industry interviews.

1) Literature Searches:

a) Literature search of federal environmental legislation affecting mines and smelters from the Federal Legal Information Through Electronics (FLITE) system.

b) Information searches through Dialogue Information Services, Defense Technical Information Center (DTIC), Defense Logistics Studies Information Exchange (DELSIE), and others.

c) Literature and information about domestic mineral reserves, mineral production technologies, etc. from several government agencies to include the Environmental Protection Agency (EPA), Bureau of Mines (BM), Bureau of Land Management (BLM), and Geological Survey (USGS).

d) Literature and information about industry trends, industry interaction with government, etc. from the American Mining Congress (AMC), and reports from U.S. Congressional Committee hearings.

2) Interviews. From the information gathered in the literature searches the next step was to conduct non-structured interviews by phone with people in government and industry that are involved either in the strategic minerals (chromium or PGM) problem, or mining environmental problems. Interviews were done with representatives from the Bureau of Mines (commodity specialists, chemical engineer), Environmental Protection Agency (Air, Water, Solid Waste, Technology), Mine Safety and Health Administration, American Mining Congress, and the Stillwater Mining Company. This was done to determine the nature of the actual situation apart from what is reflected in the literature. Each interview involved different questions relevant to the organization represented but the general direction of the questions were as follows:

1) To what relative extent (if any) have domestic in-ground resources of chromium and PGM been kept subeconomic by the added cost burden of complying with environmental legislation?

2) Is the government assisting the mining industry's transition into compliance with environmental legislation?

3) How directly are the various agencies (BM, BLM, USGS, EPA, etc.) involved in working strategic minerals and/or mining industry problems?

4) What agencies get involved in the Environmental Impact Statement process?

5) How are subeconomic domestic resources of chromium and PGM taken into account (if at all) in strategic minerals planning?

6) What are the current moves (if any) toward solving some of the difficulties the metals (especially chromium and PGM) mining industry has experienced in the last ten years.

Justification. This exploratory methodology is necessary in order to answer the investigative questions and make sense of the issue as a whole. This study seeks to lay groundwork for future policy-making studies in the area of chromium and PGM domestic resource issues.

Overview

The following chapter describes chromium and PGM in terms of uses, international market aspects, world geographical distribution, and general geological deposition; the discussion then focuses on the overall area of conflict between federal environmental policy and the mining industry. Chapter three describes the domestic resources of chromium and PGM by deposit, first for the lower 48 states and then for Alaska. Chapter four discusses the major pieces of federal environmental legislation affecting the mining industry and the agencies involved in this process, followed by a case study of the Stillwater mining project. Finally, chapter five has a summary of the chapters, followed by conclusions and recommendations, and recommendations for future study.

II. Background

Introduction

This chapter will introduce the current national and international picture for chromium and platinum-group minerals and for the U.S. metals mining as a whole. Definitions of terms for a particular subject are listed in the section pertaining to that subject.

Chromium

Definitions.

Chromium. A basic metallic element (Cr) that does not occur naturally in pure form but in combination with other elements.

Chromite. A naturally occurring mineral in the spinel group with isometric crystal structure and a pure state formula of $FeO \cdot Cr_2O_3$. With naturally occurring replacement the formula for chromite will vary within $(Fe, Mg)O \cdot (Cr, Al, Fe)_2O_3$ having different spinel minerals occurring in typical chromite ore. Chromium occurs in other minerals but chromite is the only ore mined for its chromium content (43:4).

Chromic Oxide. Chromic Oxide (Cr_2O_3) is the way that chromium is found in chromite and is the measuring standard for chromite purity.

> The chromic oxide (Cr_2O_3) content of pure chromite by weight is 67.9%; chromium content, 46.5%. Chromite ore rarely contains more than 50% Cr_2O_3, and other minerals, such as silica (SiO_2), also occur [43:4]

Ferrochromium. A metal made to be used as an important alloy in steelmaking, especially stainless steel. There are two basic grades of ferrochromium: high-carbon (3% or more carbon) ferrochromium, and low-carbon (less than 3% carbon). Low-carbon ferrochromium is more refined and more expensive (44:10).

Uses. Chromium adds important heat and corrosion resistance properties to stainless steel and other steel alloys. No substitute has been found for chromium in the steel-making process (11:2). The largest defense industry consumption is in the areas of aircraft engines and parts, guided missiles, electronic components, shipbuilding, and ammunition (31:68). Chromium is also used in refractory bricks for iron and steel production, and in a number of chemical applications.

Grades. Chromite (mineral form) is atomically arranged to have some replacement with either chromium, iron, magnesium, or aluminum (10:424,429). There are three market grades of chromite: metallurgical (high chromium), refractory (high aluminum), and chemical (high iron). The U.S. Treasury Department recognizes three classes of chromite ore and ore concentrate for taxation based on the Cr_2O_3 (chromic oxide) content. The metallurgical grade contains 46% or more Cr_2O_3, refractory grade is less than 46% but more than 40%, and chemical grade is 40% or less (43:4). With new technologies in processing the grades have become more interchangeable. Approximately 90% of U.S. chromite consumption is by the metallurgical and chemical industry with the remaining 10% consumed by the refractory industry (42:36). The only grade of concern here is metallurgical. Alternate methods for reducing chromium requirements in various applications are being studied. Foster estimates that:

Present U.S. chromium consumption could be reduced by approximately one-third by using available technology to substitute alternative materials and processes, to recover and recycle waste chromium,and to design for greater chromium efficiency [19:2].

A number of things that were not economical or neccessary in the past are now proving to be useful, like near-net shape casting, more efficient recovery in the mining and smelting processes, etc.

International Market.

Chromite Production. South Africa and the Soviet Union produced about 62% of the world's chromite in 1986 with the rest divided between India, Turkey, Albania, Zimbabwe, Philippines, and a few minor producers. The U.S. imports for 1986 totaled 488,203 short tons of chromite in all three grades from South Africa (60.8%), Turkey (19%), the U.S.S.R. (4.4%), Philippines (3.8%), and Canada (2.6%). The metallurgical grade imports totaled 218,203 short tons of chromite from South Africa (99.8%), and the Philippines (0.2%). Again, industry is able to utilize lower grades of chromite than previously (44:9,15). All chromite ore consumed in the U.S. is imported.

Ferrochromium Production. Due to the diminishing smelting capability in this country much of the chromium-containing material is imported as low or high-carbon ferrochromium, ferrochromium-silicon, or chromium metal. This also reflects the trend of some foreign mining concerns to have smelting facilities near the mines in order to save transportation costs and reap some of the profit traditionally taken by more industrialized societies.

Analysis of chromite, chromium ferroalloy, and metal imports on a chromium contained-weight basis shows the trend over the past 10 years has been to obtain increasing quantities of chromium as chromium alloys. In 1973, chromite imports exceeded those of chromium ferroalloys and metal by more than a factor of two. In 1981, chromium ferroalloy and metal imports about equaled chromite imports. In 1983, chromium ferroalloy and metal imports exceeded chromite imports by more than a factor of two [43:8,9].

In 1986 the U.S. imported 398,000 short tons of chromium ferroalloys (high/low-carbon ferrochromium and ferrochromium-silicon). Imports for high and low-carbon ferrochromium were from 9 different countries with 96% coming from South Africa (61%), Turkey (13%), Zimbabwe (11%), Yugoslavia (7%), and Finland (4%) (44:10).

Geographical Distribution. World production and distribution of chromite reserves are estimated by the Bureau of Mines in table 1 (42:37).

Geological Deposition.

Stratiform Deposits. Currently, the largest economic sources of chromite are in continental stratiform deposits and are usually high in iron. The biggest producers of this type are the Bushveld Complex in South Africa and the Great Dyke in Zimbabwe which exhibit consistent chromite layering and banding over large lateral displacements (11:5-6). Although podiform deposits have produced more chromite to this point in history, stratiform deposits will be most important in the future because of the massive size of stratiform reserves: Bushveld Complex - 2500 million tons, Great Dyke - 420 million tons (52:7). Stratiform deposits are usually associated with igneous intrusives and are thought to get their mineral banding and orientation from a magmatic segregation process (10:432).

Table 1. World Mine Production, Reserves, and Reserve Base: (thousands of short tons)

	1987 Mine Production	Reserves	Reserve Base
U.S.	---	---	---
Brazil	300	9,000	10,000
Finland	500	19,000	32,000
India	700	15,000	66,000
Philippines	300	15,000	32,000
South Africa	3,840	913,000	6,300,000
Turkey	600	5,000	80,000
Zimbabwe	600	19,000	830,000
Other Market Economies	300	17,000	25,000
Albania	1,000	7,000	22,000
U.S.S.R.	3,000	142,000	142,000
Other Centrally Planned Economies	60	4,000	4,000
World Total (may be rounded)	11,400	1,165,000	7,500,000

(42:37)

Podiform Deposits. The other major economic type of deposit, podiform chromite, is associated with mafic and ultra-mafic rocks and so oceanic/submantle origins rather than continental origins. Podiform deposits are important for higher grades of chromite (or high Cr and Al grades) but do not exhibit the consistency across horizon and economies of scale of stratiform deposits (11:5; 45:221). The U.S.S.R., Turkey, Albania, and the Philippines possess producing economic deposits of this type but, due to depletion, only the U.S.S.R. is predicted to be a major producer in the year 2020 (11:6,16).

Laterite Deposits. Another class of deposits is laterites from which low-grade chromite deposits associated with nickel and cobalt can be recovered. A typical origin scenario involves peridotite altering to serpentine which is subsequently weathered into a soil in a tropical environment. The weathering process leaches out several original constituents leaving a soil rich in chromite as well as nickel and cobalt (25:3; 45:458). Laterites are not currently economical to produce but may be important in the future (39:26).

Domestic Prospects. There are no domestic sources of chromite that are economical to produce now or in the foreseeable future. The Stillwater Complex in Montana is estimated to have 10^6-10^9 metric tons of stratiform chromite but it is not economically feasible to mine because of low-grade ore. Most of the ocean bottom projects have yet to demonstrate an economic grade of ore and an inexpensive method of producing the ore (54:134; 11:7). The following chapter will deal in more detail with domestic resources of chromite.

Platinum-Group Metals

Definitions.

Platinum-Group Metals. There are six closely related elements in the platinum-group metals: platinum, palladium, rhodium, iridium, ruthenium, and osmium. The two most prominent in production and demand are platinum and palladium followed by ruthenium, rhodium, iridium, and minor amounts of osmium.

Uses. Platinum-group metals (PGM) are critical as catalysts in fossil fuel processing and electronic components. The largest commercial application in the U.S. is for automobile catalysts, followed by electrical and electronic components. PGM have some very unique characteristics: high melting point, chemical inertness, and catalytic activity (28:4). There are a wide range of uses for PGM from petroleum production to medical and dental applications. The defense applications in electronics are critical and substitution studies are ongoing.

International Market. Platinum and palladium are the most widely consumed of the platinum-group metals. With demand for PGM (especially platinum) running well above supplies, the prices for PGM have been increasing from 1985 through 1987. The increased use of automobile catalysts in Western Europe has helped to keep the demand up (47:1,2,9). Recycling automobile catalysts is proving to be economically profitable, and useful to the overall domestic trade picture (27:118). The U.S. exported 750,675 troy ounces of PGM in 1986 mostly as PGM-bearing scrap in addition to the PGM processed in this country.

Of the 8 million troy ounces of PGM mined worldwide in 1987 (U.S. quantities withheld for proprietary reasons) the U.S.S.R. and South Africa split evenly 94% of the total (27:119). South Africa produces proportionally more platinum and the U.S.S.R. produces more palladium.

Geographical Distribution. The world-wide distribution of production and reserves is broken out in table 2 (27:119).

Table 2. World Mine Production, Reserves, and Reserve Base (in thousand troy ounces)

	1987 Mine Production	Reserves	Reserve Base
United States	withheld	8,000	25,000
Canada	281	8,000	9,000
South Africa	3,700	1,600,000	1,900,000
Other Market Economies	103	1,000	1,000
U.S.S.R.	3,850	190,000	200,000
World Total (rounded)	7,800	1,810,000	2,140,000

(27:119).

Geological Deposition. The origins of PGM are much the same as the mafic and ultramafic origins for chromite and the two are often associated in deposition. The areas where PGM are mined as the primary product are typically stratiform/magmatic in nature. There are also some placer deposits of minor importance as well as podiform, hydrothermal and base-metal sulfide deposits. In most places (except the Bushveld Complex and the Stillwater Complex) PGM are mined as by-products of nickel and/or copper so the amount of PGM mined is determined by whatever PGM are recovered with the amount of nickel the mine produces (45:220; 53:4,6).

Domestic Prospects. The United States has resources of PGM totaling an estimated 9% (300 million ounces) of total world resources of 3.3 billion ounces (27:119). Most of the United States PGM is in the Stillwater Complex in Montana and will be discussed in the next chapter. There are deposits worthy of note in Minnesota, and Alaska. Most PGM in the U.S.

have been mined as a by-products of copper until the opening of the Stillwater mine.

U.S. Mining Industry and the Federal Government

Despite strategic mineral imports and high domestic consumption rates, the United States is a large overall mineral producer that exports billions of dollars in minerals a year ($24.9 billion in 1981) (6:29). Currently the metal mining industry is having the same kinds of difficulties as other heavy industries in this country.

> In 1981, the U.S. metals mining was an 8.9 billion enterprise. By 1983 it had shrunk to just 5.9 billion. The jobs provided exeeded 109,000 people in 1981, and at the beginning of 1985, what remained was a workforce of about 45,000, and the prognosis is for further reduction...the farmers and the miners of this country are the source of the basic materials for all economic activity [54:51].

Many existing mines are shut down because operating expenses do not allow them to compete with international mineral price levels. Reopening a mine is expensive and unlikely unless an operation will be profitable over a number of years. Mining is a capital intensive industry that requires long lead times from discovery to production. Many projects are abandoned at the concept stage. Two problems that appear to be seriously hampering the mining industry are: 1) the inability to expand because of federal land restrictions, and 2) the expense and difficulty of making operations comply with federal environmental regulations (54:54; 51:1079).

Much of the land that would normally be considered geologically "ripe" for mineral exploration is owned by the federal government and has never

been subject to modern exploration techniques. There are nearly 800 million acres of federal land in the western states and Alaska (6:23; 51:1072). Some mountainous areas have been declared federal wilderness areas for the specific reason of preventing mining operations. Even if private exploration were allowed there would be little incentive for mineral companies to invest in expensive exploration with no assurances that they would be able to develop any discoveries made (54:54). Another difficulty with Alaska, as with many remote regions of the world, is the lack of rail transportation or roads (infrastructure) in the interior regions (6:24). It would be very difficult to develop profitable mining operations with those kinds of limitations.

Current environmental statutes and regulations in the U.S. make mining operations and mineral processing plants much more expensive to run than in years past:

> The proportion of capital spending by the mineral industry for pollution control exceeds that of all other industries . . . minerals processing produces significant amounts of sulfur oxides and therefore was heavily impacted by the provisions of the Clean Air Act [6:44].

Between 1973 and 1979 the metals industries paid $5.5 billion for pollution control (6:44). Often pollution statutes are made without regard to overall impact on the industries they affect. This makes current facilities unprofitable and discourages investment in new facilities and operations (54:54).

Although the Congress and the Executive branch have addressed strategic minerals issues and initiated statutes and programs to deal with them, little action has been taken to implement these directives. The

government has opted to regulate the mineral related industries in levying pollution controls and federal lands restrictions, but has provided little or no compensation by way of protection from market forces (54:51). Budget constraints have, in part, kept congress from interceding on behalf of mines and smelters being undersold on the international market. Foreign competitors are often subsidized by their own government. Industry difficulties often compound:

> The loss of smelting capacity has reduced the economic feasibility of mining low-grade ores in the United States, resulting in a trend toward importing processed critical materials [6:41].

The economic reasons for smelters locating closer to mining facilities are sound ones: much lower transportation costs for shipping secondary product rather than raw ore and, production rates of the mines and smelters can be closely coordinated. Allowing mines and smelters to go out of business, however, has created some potential national security problems for this country. Without sufficient smelting capacity the U.S. loses its flexibility on the international markets as well as at home. The choice of material suppliers becomes narrower as material specification becomes narrower (11:3).

Land Use Issues. All the variables are present for the United States to have more domestic supplies of strategic minerals. With the fourth largest landmass on the earth, and much of it unexplored, the potential for undiscovered mineral deposits is significant (51:1071). The technological and monetary base is available to develop better, cleaner mining and processing techniques (11:4).

Commentary

The interviewees reaffirmed the literature that recycling remains the only source of domestic chromium currently available to industry. The PGM recycling business is quite profitable with most of the PGM coming from catalytic converters taken off of salvage autos.

Summary

Domestic chromium and PGM mining operations would be advantageous for national security, defense industry, and national economic reasons. However, the problems of Federal land use and pollution control are proving to be very real "show stoppers" that represent conflicts of interest from the highest levels of government to the community level in this country. This is partly evidenced by the amount of unenforced legislation in place to help the minerals industries while opposing pollution and land-use laws are being strictly enforced (54:52).

A large part of the availability problem is the lack of clearly economic reserves of chromium and PGM in the U.S. In order to formulate national plans and policies for strategic minerals it is neccessary to know what resources of these two minerals exist; the known resources of domestic chromium and PGM are described in the following chapter.

III. Domestic Prospects

Introduction

In the literature dealing with strategic minerals, references to domestic resources of chromium and PGM are generally passed off as being subeconomic or in the development phase. The emphasis is usually placed on what is currently useful or expected to be useful in the near future. In this chapter known resources of any size that could conceivably be useful in the future are described. Usefulness is determined by virtue of total mineral volume in a deposit (even at low concentration) or by virtue of high concentration even with lower volume (i.e. easy to get at) keeping in mind a hypothetical national emergency situation where market price becomes much less important. A number of source articles list rounded estimates in metric tons, but for consistency this paper will list all references in short tons (1 short ton = 2000 lbs.).

Chromite

Introduction. There are considerable chromite resources in the United States that are mostly subeconomic at current prices; the mineral concentration is so low that it would cost more to mine it and mill it than the end product could be sold for on the open market. Some deposits are extensive while others have not been adequately investigated. There is considerable exploration work left to be done, especially in Alaska. On a world-wide basis chromite is quite abundant and market prices reflect that. There are a number of countries whose economies depend to some larger

degree on exporting chromium, and they actively promote (and/or subsidize) chromium mining and production. What follows is a series of descriptions of domestic chromite deposits with estimates of their potential for exploitation, and the degree to which they are known or understood.

Definitions.

Strike/Dip. Strike and dip are two ways of describing the position of a rock bed in relation to the surface of the earth. Dip measures the angle at which the bed descends into the earth relative to horizontal. Strike measures the horizontal azimuth perpendicular to dip.

Mafic/Ultramafic. Igneous rocks are generally measured in terms of silica percentage; ultramafic rocks are igneous rocks that have <45% silica, and mafic rocks are igneous rocks have 45-52% silica. The silica content is important because it helps to define rock and mineral associations in a given depositional environment. For instance, ultramafic rocks generally contain no quartz or feldspar but do have Mg-Fe silicates. Mafics and especially ultramafics are generally made up of darker minerals. Typical examples of ultramafic rocks are dunite and peridotite and for mafic rocks, basalt and gabbro (24:39,42). The rock and mineral associations as well as chemical composition ranges for these igneous classifications are quite complex and outside the scope of this study.

Ophiolite. A group of mafic and ultramafic rocks usually with a specific order or sequence of rock types that are indicative of the depositional environment of the assemblage. In an oversimplified explanation, an ophiolite complex is thought by some to be a chunk or cross-section of former oceanic floor crust that ended up on a continental mass by the turmoil of plate subduction.

Metamorphic Suite. When rocks (for this study igneous rocks) are subjected to heat and pressure, at some point that they are altered physically and chemically to find a new equilibrium and are considered to have been metamorphosed. Igneous rocks formed originally from molten rock (generally) whereas metamorphic rocks are altered versions of other rocks. In a metamorphic suite there are certain rock mineral associations just as in igneous rocks because under given heat and pressure conditions, specific igneous minerals will alter to specific metamorphic minerals. Metamorphic rocks are affected by the stress of their deformation demonstrating mineral orientation in relation to stress patterns and directions. So, theoretically, the heat, pressure, and rock types involved in a metamorphic event(s) can be traced given the structure (mineral orientation, foliation), metamorphic rock and mineral associations (what altered and what did not), and the rocks that the suite grades into. The subject of metamophic mineral associations and chemical equilibria is quite complex and beyond the scope of this study.

Contiguous United States (CONUS). Most of the massive, easily accessible, high-grade podiform ore in the CONUS has been mined in the past century. There are still considerable amounts of chromium to be mined in the CONUS but few, if any, deposits are currently economical to develop. The total amount of low-Fe, Cr_2O_3-bearing ore, which is all found in podiform deposits is some 16,093,580 short tons which averages 10.6% Cr_2O_3 (1,705,919 st of contained Cr_2O_3). The total amount of high-Fe, Cr_2O_3-bearing ore to include stratiform, placer and podiform deposits is estimated at 152,668,550 short tons that averages 9.0% Cr_2O_3 (13,740,170 st

of contained Cr_2O_3) (58:31). The following section lays out the nature and dimension of the potential chromite resources in the contiguous 48 states.

Figure 1. Locations of Chromite Deposits in CONUS (58:38)

Montana.

Stillwater Complex. Located on the north side of the Beartooth Mountains in southern Montana, the Stillwater Complex is the largest and most consistent ore body for chromite (and platinum) in the

United States. The exposure is some 45 to 48 km long and is 7.8 km wide at its widest point, averaging between 3 and 6 km wide (58:33; 52:315). The chromite is disseminated and the complex as a whole is of stratiform nature. That means that the ore is distributed relatively evenly throughout the ore bodies rather than being in lumps and pockets like podiform deposits. The Stillwater is an igneous body of rock that intruded as magma into the host rock and is layered due to diffusion and magmatic segregation. The whole complex was thought to have been deposited in a horizontal orientation and has since been deformed to dip steeply and in some places actually overturned (30:1).

> The complex, for classification purposes, has been divided into three zones, the Basal, Ultramafic, and Banded Zones. Chromite is concentrated in 13 separate, alphabetically designated (oldest to youngest) chromitite layers within olivine-rich rocks of the Ultramafic zone in the lower part of the complex . . . only two, the G and H layers, are believed to contain potential chromite resources [58:33,34].

The the olivine-rich rocks in the Ultramafic zone are known as the Peridotite member of the zone. Within the Peridotite member are cyclic units thought to have formed by crystals settling out of a cooling magma. These cyclic units contain the chromite layers (30:1).

A fair amount of chromite has been mined in the complex under government contract in the past. The Benbow and Mountain View Mines were developed on and off during the early 1900's but most recently during the Korean War. Nearly one half million tons of chromite ore from the Mountain View Mine were stockpiled near the mine from 1961 until the government sold half of it in 1974 then moved the rest of it to Columbus, Montana in 1982 (58:34; 50:2). The Nye Basin Area and the Gish Mine were

explored during the 30's and 40's. Some ore was mined at the Gish mine but never milled, while the Nye Basin has never been developed (58:34).

The Stillwater Complex has not been mined for chromite since 1961 (nor has any other U.S. prospect). The grade of the chromite is considered low by world standards, although it is consistent throughout the complex. In actual numbers, the Stillwater Complex (including the four sites listed above) is estimated to contain 46,783,000 short tons of chromite with an average of 22% Cr_2O_3. The depth of the complex for obtaining that figure was set at the level of the Stillwater River, which probably makes the figures conservative (58:34).

Commentary. Some of the other factors that make this area subeconomic for chromite mining are high U.S. labor rates (more precisely, low labor rates in South Africa and Soviets selling ore at a loss), high transportation costs, and the costs of meeting state and federal environmental requirements. The costs of the environmental aspects will be discussed in detail in chapter 4. The transportation costs are important, especially in relation to the processing costs. According to one individual interviewed, it is more expensive to ship chromite ore to the east coast from Montana by train than from South Africa by ship. That also has to do with shipping raw or roughly milled ore. Having smelters near the mine sites, hence, shipping higher grade chromium, dramatically reduces shipping costs. When foreign sources are able to do that and domestic producers are not, it effectively raises domestic transportation fees and works to keep U.S. resources subeconomic.

Red Lodge District. The Red Lodge mining district is in the Beartooth Mountain range approximately 25 miles southeast of the Stillwater Complex . Chromite occurs here in association with ultramafic rocks that have been metamorphosed to mostly serpentinites and hornblende/clinopyroxene. Because of the metamorphism that has happened to the original rock, the nature of the ore deposition (stratiform or podiform) has remained a matter of question (29:1-2).

Most of the chromite ore was mined from this area between 1941 and 1943 with remaining estimated resources of 19,800 short tons at 30% Cr_2O_3 (58:34). The remaining ore is high in iron and not as easily accessable as the ore that was originally mined; the chromite remaining occurs as accessory minerals rather than massive ore (29:1,31).

Table Mountain Prospect. Located in the Spanish Peaks Primative Area, the Table Mountain prospect contains chromite that is both low-grade (11% Cr_2O_3) and relatively high in iron (Cr-Fe ratio1.6). Occurring in a mostly metamorphic suite of rocks, there is an estimated 358,000 short tons of ore in this area (58:34).

California.

Siskiyou County.

Seiad Creek District. The chromite deposits in the Seiad Creek district are located near the California-Oregon border around 123 degrees west in the Klamath Mountains. The mountain range is part of an ophiolite complex that runs north to south. The ore deposits are in dunite and peridotite sections of the complex. There are four deposits in the Seiad Creek district (Seiad Creek mine, Emma Bell deposit, Anniversary

deposit, and the Black Eagle deposit) and all of them occur in the dunite section except one that occurs in harzburgite (very near the dunite body).

The Bureau of Mines has done a lot of exploration work in this area beginning in the 1940's. Chromite was mined from the Seiad Creek mine during both world wars but the amount mined was relatively small compared to what is estimated to remain there. There are an estimated 1,886,000 short tons of chromite with an average of 6% Cr_2O_3 at the Seiad Creek mine (9:6,7).

The Emma Bell deposit is rather low-grade (5% Cr_2O_3) on average with some areas higher than others (9:7). The low-grade area is around 3.5% Cr_2O_3 while a higher grade band of an estimated 13.8% Cr_2O_3 is some 4 to 10 meters wide. The total deposit size is estimated at 1200 meters along strike by a width of 20 to 60 meters (9:7; 58:35). The high-grade chromite reserve is estimated at 3,730,000 short tons of ore, and with the low grade ore added in the total would be 16,047,000 short tons of ore.

The Anniversary deposit is where the chromite occurs in harzburgite and is only estimated to contain 5,250 short tons of chromite at 5% Cr_2O_3. The Black Eagle Deposit contains an estimated reserve of 3,000 short tons of chromite also at 5% Cr_2O_3 (9:7,8).

Hamburg-McGuffy Creek Area. About 25 miles (40 km) south of the Seiad valley lies a complex of ultramafic rock with chromite deposits in the Ladd and the Tom Martin Ultramafic bodies. The Ladd body is mainly composed of dunite, clinopyroxene, wehrlite, and lherzolite, while the Tom Martin body is mostly hornblende-bearing harzburgite and several other hornblende-bearing minerals as well as gabbro and dunite.

The Ladd mine has some higher and lower grade areas but a combined estimate gives 3,855,000 short tons of ore at 5% Cr_2O_3. The Hamburg-McGuffy Creek area (Tom Martin body) was explored and mined during World War I and further explored in World War II and not seriously looked at again until 1979. There are an estimated 460,000 short tons of ore in this area at approximately 8% Cr_2O_3 (9:8-13).

Del Norte County. There are two chromite sources of note in Del Norte county, the Bar Rick deposit and the Broken Ladder deposit. Both of these deposits contain pods, lenses, and streaks of chromite (podiform). The chromite occurs randomly and is surrounded by dunite in shear zones where the dunite has been altered (localized metamorphism). The Bar Rick has been fairly well explored and is estimated at 2,421,000 short tons of chromite at 5.9% Cr_2O_3 in the best areas with another 24,708,000 tons of low grade chromite at 2.8% Cr_2O_3. The Broken Ladder deposit has not been extensively explored but is estimated at 6,614,000 short tons at 5% Cr_2O_3 (58:36).

El Dorado County. There are a number of chromite deposits in El Dorado county and chromite is found in a number of depositional forms ranging from podiform to stratiform. The Pilliken Mine area is of most interest with some nine districts containing an estimated 3,620,000 short tons of chromite averaging around 10.5% Cr_2O_3. There is a considerable amount of low-grade ore - 46,040,000 short tons at 3.2% Cr_2O_3. The low-grade ore is also high in Fe which makes it less valuable (58:36).

San Luis Obisbo County. A number of chromite deposits have been worked in San Luis Obisbo county in the past (since the 1870s).

Little or no exploration has been done since the 1940s. The estimates for high grade ore (>10%) are insignificant but:

> Although the Bureau [of Mines] has yet to determine the potential of chromite resources in lower grade deposits containing 5 to 10 pct Cr_2O_3, the probability is high of discovering large tonnages of low-grade resources similar to those described in Siskyou, Del Norte, and El Dorado Counties. These deposits should be investigated in order to properly ascertain their potential [58:36].

This county typifies the shift from mining high-grade podiform deposits to the lower grade stratiform deposits. The podiform deposits were cheaper to mine and to process but were inconsistent and mostly low volume while the stratiform deposits tend to be much larger, much more consistent, and allow high-volume mining (26:4,5).

Tehama County. The podiform deposits in Tehama county have been worked in the past and are estimated to contain 115,000 short tons of chromite at 11.9% Cr_2O_3 while the past ores were about 45% Cr_2O_3 which would probably be economic by today's standards. As with most domestic podiform deposits the richest and easiest access ores have been mined. The Tehama county deposits occur mostly in the North Elder creek area in a shear zone of altered dunite. The Bureau of Mines suggests that there may be other undiscovered deposits further down strike of this zone (58:37).

Laterite Deposits. There are significant laterite deposits in southern Oregon and northern California resulting from weathering and alteration of the peridotite belts in the Klamath Mountains mentioned earlier. The laterites are in the form of soils that can be processed for the recovery of chromium, nickel, and cobalt. The Bureau of Mines has

developed some recovery procedures for laterites but their conclusions for chromium are:

> The magnesia, alumina, and iron contents of the chromite associated with domestic laterite limit the attainable product grade. In addition, the fine particle size of much of the chromite limits recovery of the mineral, the grade, and the ultimate use of the concentrate. The chromite has neither the size distribution nor the composition preferred for refractory or metallurgical applications [25:20].

The chromium recovered from laterites would be best suited for use in chemical applications (25:19).

Placer Deposits. There is one placer deposit of note south of Crescent City that is estimated at 772,000 short tons of ore in black sands at 7% Cr_2O_3 (58:37).

Oregon.

Josephine Peridotite. The Josephine Peridotite is the most extensive body of rock in Oregon in which chromite is found. The deposits of chromite are all of the podiform variety and are found across several counties: Josephine, Curry, Douglas, Jackson, and Coos county. Data for a number of the areas is unavailable but the deposits are mostly high grade (45% Cr_2O_3) and low volume (nothing over a few thousand tons). There are some lower grade deposits in the Chrome Ridge area with an estimated 718,000 short tons of chromite ranging from 5% to 19% Cr_2O_3 with an average of 8.6%. The Bureau of Mines feels that there are potentially more reserves that could be revealed with more exploration and detailed mapping (58:38).

John Day Area. Situated in Grant county, the John Day area has three notable deposits of high alumina (Al_2O_3) chromite estimated

to total 208,000 short tons at 22.5% Cr_2O_3. This chromite occurs in serpentinized dunite in depositional forms ranging from disseminated to podiform (58:38).

Placer Deposits. There are large low-grade placer deposits on the southern coast of Oregon that were worked during World War II and the Korean War. A total estimate of the 13 most significant deposits and a group of small ones is 8,894,000 short tons of ore at 4.8% Cr_2O_3 (58:39).

Washington.

Twin Sisters Range. In the northern Cascades Mountains, the Twin Sisters Range contains a massive block of dunite which is estimated to contain 518,000 short tons of chromite with 6.5% Cr_2O_3, with the potential for a high volume of lower grade material (58:39).

Cle Elum and Blewett Pass. There are iron ore deposits at Cle Ellum and Blewett Pass that are collectively estimated to contain 8,335,000 short tons of iron ore that have an average of 2.6% Cr_2O_3 (58:39).

Wyoming. The Casper Mountain deposit is composed of an actinolite-talc shist with an average of 2.5% Cr_2O_3 in 4,161,000 short tons of shist. Included in that figure is 575,000 short tons at 8.7% Cr_2O_3. These figures are likely conservative estimates (58:39).

Appalachian States. Because of low concentrations of Cr2O3 the Appalachian deposits wil likely remain insignificant.

> . . . Resource estimates were made by the Bureau of Mines for 18 placer deposits derived from weathering of the podiform deposits. . . Resource estimates for 9 deposits in Maryland, 5 in Pennsylvania, 3 in North Carolina, and 1 in Georgia total 1,247,000

mt [metric tons - 1,374,568 short tons] averaging 1.4 pct Cr_2O_3 for the 18 deposits [58:40].

Alaska. The Alaskan chromite deposits have been explored and described in a much more general way than the CONUS deposits and, in general, are less well known than those of the lower 48 states. The Alaskan resources are estimated at 3.4 to 4.3 million short tons of contained Cr_2O_3; these are conservative estimates subject to stringent requirements listed below (17:29).

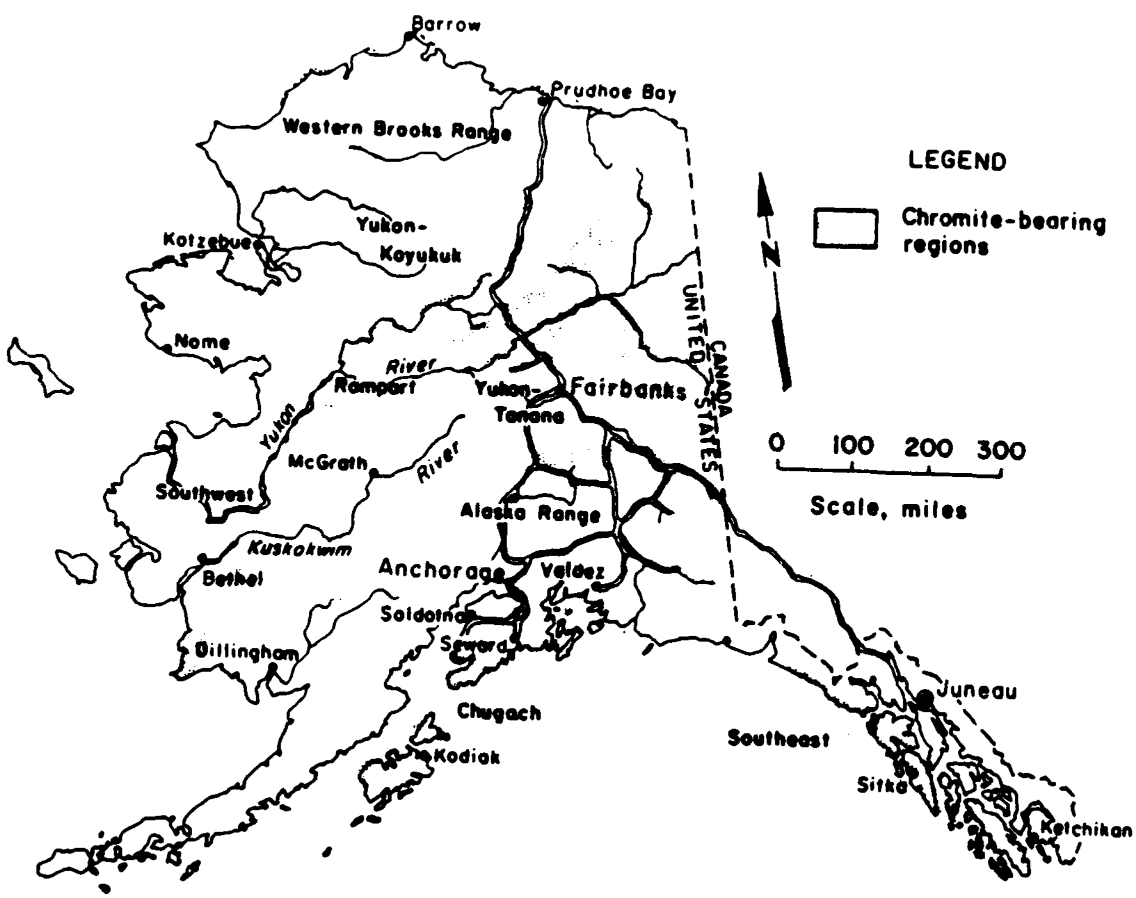

Figure 2. Chromite-Bearing Regions in Alaska (17:24).

Chugach Trend. The Chugach trend describes a zone or band of rocks that occurs alongside the Border Ranges Fault across southern Alaska.

The Border ranges fault is thought to be a tectonic boundary where the Pacific plate was being subducted in a past geologic time (16:5). The fault is roughly an arc shape (like the southern Alaskan coastline) that is 50 to 70 miles inland at some points and then goes out the Kenai peninsula and across Kodiak Island. Chromite deposits occur in a number of areas along the trend, mostly on the north side of the fault. The Bureau of Mines study from 1981-1983 examined 94 "chromite occurrences" from which they identified 41 hard-rock deposits and one placer deposit of potentially exploitable chromite (16:1,6). The deposits identified were subject to several arbitrary requirements:

> 1. Access route must not exceed 10 miles to tidewater or existing transportation systems.
>
> 2. Chromite contained in these deposits must be recoverable to meet metallurgical-grade specifications; that is, a product containing a minimum of 46 pct Cr203 at a Cr:Fe ratio of nearly 2.0 or greater must be obtainable through the use of standard concentration techniques. Chromite concentrations and Cr:Fe values from all deposits sampled in a given ultramafic complex were considered to determine if that complex hosts chromite that could be concentrated to meet metallurgical specifications. If the values did not meet these specifications, no recoverable chromite was inferred for that complex. Chemical- and refractory-grade chromite deposits were described but not included in the compilations.
>
> 3. Deposits must be amenable to low-cost bulk mining methods, such as open pit or block caving operations. Concentration of low-grade ores by sorting and gravity methods would be required to produce shipping concentrates that meet industrial specifications.

4. Chromite content in some of the lode deposits was visually estimated. Only lode deposits containing a minimum of 5 pct chromite were included in the compilations.

5. Placer deposits were evaluated on the basis of Cr_2O_3 assays and must contain a minimum of 1 pct Cr_2O_3.

6. Deposits containing less than 1,000 [short] tons of Cr_2O_3 were not included in the compilations [16:7,8].

The above requirements bring out an important point about exploration in wilderness areas and especially Alaska; the potential for new discoveries is considerable. The limitations on exploration have a lot to do with the lack of infrastructure (roads, railways), massive vegetation, inhospitable weather, and lack of funds (hence, manpower).

The mineral and rock associations are fairly typical for podiform chromite deposits:

> The crudely to complexly layered ultramafic and mafic-ultramafic complexes consist primarily of variably serpentinized dunite, peridotite, and pyroxenite, with associated gabbroic rocks in some of the complexes. The proportions of these lithologies vary among the complexes; of the ultramafic rocks, dunite is generally the most abundant, with lesser pyroxene peridotites including harzburgite, wehrlite, and lherzolite [16:6].

The mafic and ultramafic complexes are thought to be masses of oceanic crust put in place by a subduction trench tectonic event. The Chugach trend represents the only area that has had previous chromite production as well as being the feature with the largest estimated or inferred reserves in Alaska. Within the standards listed above the Bureau of Mines total estimate for the Chugach trend is 2,200,000 short tons of Cr_2O_3 contained in chromite that is high in Cr (metallurgical grade) (16:1).

The authors of the Alaskan studies did not list the values in tonnages of chromite but rather in contained Cr_2O_3.

Western Brooks Range Trend. In northwestern Alaska in an east-west belt that runs from 250 miles inland to the Bering Strait there are 70 chromite deposits with a roughly estimated 576,000 to 1,400,000 short tons of Cr_2O_3. Some of the chromite deposits are high-Cr and some are high-Fe (17:27). Again, this type of exploration could be compared to a thumbnail sketch:

> These estimates are based on traverses made by four people in a 200-mi^2 area [author estimates Western Brooks Range trend area at 4000-mi^2], during two 2-week periods, and additional deposits undoubtedly exist. Next to deposits in the Chugach trend, deposits at Iyikrok Mountain and in the Avan Hills are the most likely to be developed, as they would be made accessible by a proposed road from a port site in the Bering Sea coast near Kivalina to Red Dog lead-zinc-silver deposit, where production may begin as early as 1989 [17:28].

The idea of multiple usage is important when dealing with infrastructure problems so that no single industry or concern is forced to fund large road building, track laying, and communication projects. From the other side of the issue, having multiple, cooperative, or partially subsidized funding for infrastructure opens up possibilities for projects that otherwise would not be considered.

Yukon-Koyukuk Trend. Located in central Alaska north of the Yukon River, the Yukon-Koyukuk trend has several chromite-bearing complexes within it. The two areas of most interest are the Caribou Mountain and the Kanuti River ultramafic complexes, but the exploration has been cursory and mostly in connection with the Alaska Pipeline project

(18:1,17). There are a number of deposits that are less than 1,000 short tons of Cr_2O_3 but one deposit contains 13,000 to 26,000 short tons at Holonada (17:28). As for the completeness of the exploration and study done in this area:

> The belt comprises six complexes of which the three closest to the pipeline corridor were investigated . . . It is recommended that a low-cost means of subsurface exploration be employed to establish the extent of chromite occurrences discovered during the course of this investigation . . . Additional reconnaissance is recommended within the Holonada ultramafic complex at the southwestern end of the Caribou Mountain-Melozitna ultramafic belt. This complex has not been investigated for chromium resources and may contain additional deposits of chromite [18:1,17].

__Southeast Region.__ In southeast Alaska in an area extending northwest and southeast from Sitka there are a number of small chromite deposits.

> The only complex in southeast Alaska for which resource estimates are available is Red Bluff Bay on Baranof Island, where 32,000 st [short tons] of low-grade material with about 12 pct Cr_2O_3 [3840 short tons] is present in eight deposits that compromise small lenses, thin layers, and disseminated chromite in dunite [17:27].

The island areas in southeast Alaska should be comparatively (to inland regions) easy to access for development.

__Rampart Trend.__ In a southwest-northeast trending belt in northeast Alaska, the Rampart trend is an ophiolite complex that has 4 (of 21 identified) potentially useful deposits in one area that contain an estimated 17,000 to 37,000 short tons of Cr_2O_3. Foley says "there are no roads, and access to this region is generally difficult" (17:28).

Alaska Range Trend. There are a number of reported chromite deposits in the Alaska range but none of them have available estimates for volume and Cr_2O_3 content. Helicopter is the only way to get to the deposits in question. "Chromite is reported at several locations in the Lacuna and Yentna Glaciers area, where the largest occurrence is an 8-ft by 60-ft lens of massive, high-Cr chromite (17:28).

Platinum-Group Metals

Introduction. The PGM deposits of interest tend to be of a somewhat different nature than chromite. Because of the high market value of PGM (especially platinum) the concentrations that would be considered economical are measured quite differently. Whereas chromium occurs in a mineral chromite and is tied up in chromic oxide (Cr_2O_3), PGM occur more in elemental form as metallic grains in different minerals. For instance, PGM may occur in chromite. PGM are measured in troy ounces per ton of ore. The literature on PGM deposits is also different (because PGM occur in different ways) so that a focus is placed more on being able to detect all the PGM (the concentration) that is really present in a particular area than defining the absolute total estimate for a deposit.

Contiguous United States.

Montana.

Stillwater Complex. The general description of the Stillwater Complex is described above in the section on chromite. The platinum resources which are currently being mined are described as follows:

> The Stillwater Complex contains 225 million ounces of PGM of which 80 pct is recoverable. The precious metals are associated with iron, nickel, and copper sulfides that occur in mineralized layers of the Banded Zone approximately 5,000 ft above the base of the complex. The ore body is continuous for about 24 miles [60:2].

A further description of the rock types and assessory minerals:

> The estimated composition of the Stillwater complex magma is very similar to that of the Bushveld complex of South Africa. Likewise, with respect to layering, the Stillwater complex and the Bushveld complex closely parallel each other . . . Mineralogical examination of a sample of the Stillwater ore showed that the major minerals are calcic plagioclase, clinopyroxene, orthopyroxene, and olivine. A minor amount of serpentine is also present. Assessory minerals include pyrrhotite, pentlandite, pyrite, chalcopyrite, and magnetite . . . Because of the mineral composition and texture, the rock is classified as a gabbro [59:2].

The Stillwater mining project is progressing well despite the lackluster performance of platinum and palladium on the international markets in early 1988 (48:20). The ratio of palladium to platinum in the Stillwater ore is higher (3.5 to1) than originally expected (3 to1). And with the difference in prices (between Pd and Pt) that may create longer term financial difficulties. The average price of platinum in 1987 was $556 per oz and the average price of palladium in 1987 was $132 per oz. The Johnson-Matthey annual report projects that Stillwater production for 1988 will be about 33,000 oz of platinum and 110,000 oz of palladium (48:20). For platinum, the projected 1988 production would have covered 3.4% of 1986 U.S. demand (983,000 oz) and the projected palladium production would have covered 10.4% of 1986 U.S. demand (1,056,000 oz) (28:10).

The Stillwater is producing between 0.6 and 0.83 oz combined of platinum and palladium per short ton of ore (1:7). The current operating

rates of mining and milling are at 700 short tons per day with the mine operating 5 days per week and the mill 7 days per week. The mine built up a stock of ore before the milling operation got under way (50:1).

The Stillwater project is currently paying to get the mill concentrate to a foreign smelter:

> At present, concentrates from the mine are processed by Metallurgie Hoboken-Overpelt, in Belgium but time and cost factors associated with shipping the concentrates that distance have led to considering construction of an on-site smelter. If a smelter is built, it would produce a matte with an average of $250/tr oz [troy ounce], which would be sent to an outside refinery. Present shipping costs are about $100/st [short ton] concentrate, and smelting and refining charges add from $30 to $40/st. Under the present arrangement, Stillwater gets 93% of the platinum and 94% of the palladium, while Hoboken-Overpelt retains all byproduct copper, gold, nickel, rhodium, and silver [46:31,32].

Matthey says that a decison about the on-site smelter will not be out before September 1988 (48:21).

Minnesota. In northeastern Minnesota there is an igneous magmatic intrusion called the Duluth Gabbro (DG). Within the DG is a secondary intrusive body (intruded into the DG) called the South Kawishiwi Intrusive (1:7). Both of these features are thought to have occurred in a rift environment (53:6). The two mineral zones of interest lie within those two bodies of rock.

The Ely Spruce (Inco Corp) is a mineralized zone within the South Kawishiwi Intrusive and the Minnamax (AMAX Exploration Co.) is part of the DG (1:7). Further:

Together, the two deposits contain less than 800,000 troy ounces of platinum at the demonstrated level.

Ely Spruce would most likely be mined by open pit methods, and Minnamax would be mined by various underground methods, as dictated by the nature of the ore and the host rock. For this analysis, concentrates from both deposits have been modeled to be shipped to a smelter-refinery complex to be built in Duluth, Minn.

In August 1981, AMAX announced indefinite postponement of its project owing to depressed metal prices. Work on Inco's Ely Spruce project was suspended in November 1975, following sinking of a development shaft that was completed in 1968 [1:7].

California, Oregon, and Arizona. There have been analyses done of some soils in Del Norte county as well as some rocks in conjunction with the chromite exploration mentioned above. The results have to this point shown no currently economic quantities to be present (41:6; 40:2). Samples of podiform chromite from the California and Oregon areas listed previously (and others) have been taken and analyzed for pgm with fire-assay atomic absorption and fire-assay spectrograph techniques by the U.S. Geological Survey. Nothing in the sampling even approached the Stillwater ore in terms of pgm concentration. The levels of platinum and palladium were consistently low with higher values of iridium and rubidium occasionally (7:2-11). PGM may be economical as a secondary mineral in some future copper-nickel operations.

Further south, analysis for PGM was done on ultramafic and mafic rocks from the Lost Basin mining area in northeast Arizona (east side of Lake Mead). The PGM analysis showed levels far below what is currently economical at high market prices (41:2,11).

Alaska.

Salmon River. Before Stillwater production began the Goodnews Bay Mine was the only major U.S. platinum operation. It still has produced more total platinum than any other mine:

> The Goodnews Bay mine, located along the Salmon River near the Bering Sea in western Alaska, has been the largest producer of primary platinum in the United States. Production from 1934 to 1975 totaled 641,000 troy ounces. It has been estimated that the deposit could yield an additional 500,000 troy ounces at a rate of 10,000 ounces per year, equivalent to about 1 percent of domestic platinum needs. The platinum is located within the lower 6 to 8 feet of an alluvial gravel section that measures up to 250 feet in thickness, and within the upper 3 feet of altered sedimentary and igneous bedrock . . . There is a possibility of including an underground mining operation on the deep reserve areas if technical difficulties can be overcome. Potential problems include poor roof stability and excessive water. For purposes of this report, only surface operations were considered [1:7].

The nature of the mining at Goodnews Bay is a placer operation because the platinum is in gravels. A recent study by the U.S. Geological Survey on samples from Goodnews Bay has shown that a considerable amount of platinum-group elements are not recovered because of particle sizes too small to accumulate in placers but that had occurred as "discrete grains and as inclusions in magnetite. Such grains of magnetite could easily be recovered from alluvial sediments by panning or other methods of concentration for recovery of PGE"... [49:1].

Salt Chuck Sulfide. The most notable source of PGM besides Goodnews Bay is the Salt Chuck Sulfide in southeast Alaska on Prince of Wales Island. It was a PGM producer from 1907 to 1941, with a mine and a mill that has been abandoned for some time.

Mineralization occurs in a concentrically zoned ultramafic complex within the Coast Range Intrusive. The mine produced less than 300,000 metric tons [330,690 short tons] of ore intermittently between 1907 and 1941. Demonstrated resources are less than 1,000 troy ounces of PGM, while total mineralized material at the inferred level is estimated to be only about 600,000 metric tons [661,380 short tons] at 0.014 oz/t PGM; however, there are believed to be more deposits in the area [1:8].

The PGM at Salt Chuck is associated with bornite which is typically mined for copper though it is not a primary ore like chalcocite or chalcopyrite (23:239). Those tests were not done to evaluate the ore body concentrations but to develop beneficiation techniques.

Commentary

According to the interviewees the Bureau of Mines runs field and laboratory tests on the ores from prospective chromite and PGM deposits to find the best methods of processing the ore (to get the highest percentage of metal present for the most reasonable cost). The Bureau will make this information available to interested mining concerns; if a new process is invented the Bureau often attempts to get a patent on it. The idea is to defray some of the upfront capital investment and risk for mining concerns and hopefully encourage investment in new mining ventures. For instance, the Bureau offered the Stillwater Mining Company a hydrometallic process to further refine their PGM ore but it was still less expensive to send the concentrate to Belgium for processing. That process, however, may be useful if SMC proceeds with current plans for an on-site smelter. Most of the management individuals interviewed assumed that all domestic

deposits of chromium and PGM were thoroughly searched out, which did not agree with the field reports.

Summary

The Chromium deposits in the CONUS remain subeconomic because of low-grade ore, but some of the Alaskan deposits are concentrated enough to compete except for the added expense of transportation and labor, and legal access problems in wilderness areas. The rising price of PGM over the last ten years has made the Stillwater project economically feasible and has brought others close to being possible to develop. Aside from the obvious ore grade, transportation, and labor expenses that have always been part of mining projects, is the relatively new added expense of complying with federal environmental regulations which will be taken up in the next chapter.

IV. Environmental Concerns

Introduction

There are a number of federal statutes that a given mining, milling, or smelting operation must comply with. The body of laws that developed to protect the environment began to take shape as a national policy instrument in the early seventies after a series of ineffective piecemeal laws were put forth during the sixties. A body of knowledge about the interrelationships and the complexity of the earth environment began to emerge from the seperate natural science academic disciplines in the sixties. The implication that developed and became popular from this knowledge was that the earth could not absorb pollutants as fast as modern industrial America was putting them out. Congress, concerned that previous attempts to solve environmental problems had been largely ineffective, set out to develop an overall approach designed to deal with the enormity of the problem. Congress was, it seemed, trying to stop the tide.

The environmental laws, as any laws, are largely as effective as the executive branch makes them be. Some laws were passed over presidential veto and were complied with half-heartedly. But Congress created the Environmental Protection Agency (EPA) and put some powerful tools in their hands to carry out the intent of Congress in these matters. A lot of litigation has resulted from EPA's interpretation of Congress' will and so, many issues have been defined and hammered out in court. The Supreme Court has been involved extensively in this area.

Chapter Overview. The first part of this chapter will be a discussion the major environmental statutes that would affect a given mining, milling or smelting operation and the agencies that would carry them out or be involved in the process. On the fringes of environmental issues are land use

and management issues; the latter will be dealt with only as necessary to cover the topic at hand. The way in which the main statutes are implemented at the local level makes it impossible to describe how every mining, milling, or smelting operation (even just for chromium or PGM) would or would not work out at a given location. With the current system virtually every operation is considered differently. The EPA point of view is to get control of the major contributors of pollutants; so very little or nothing is specifically directed at chromite or PGM mines. There is some mention of PGM mining because there is a minor amount going on in Alaska and within the last 18 months the Stillwater project has gotten underway. PGM are also mined as byproducts in other operations. Chromite has not been mined in this country (primary or secondary) since the early 1960's and is not addressed in EPA literature but if a project started, a special category would be developed as was the case for primary PGM mining. In order to bring together the kinds of issues, organizations, and local laws that affect a new mining concern in this country, the chapter will conclude with a case study of the Stillwater project.

Environmental Statutes

National Environmental Policy Act (NEPA). The National Environmental Policy Act (PL 91-190, 42 U.S.C. 4321-4347) was a foundational piece of legislature that brought environmental issues into governmental agency planning for the first time. Under NEPA, federal agencies are required to do an environmental impact statement (EIS) for any projects they engage in. NEPA does not force agencies to do much in response to the findings of the EIS but rather to recognize and spell out the environmental issues in a standard format for the first time (20:71).

Signed into law on 1 January, 1970, NEPA was composed of two titles:

Title 1 of NEPA emphasized the need for cooperation with state and local government. Title 1 also delineates the environmental impact statement (EIS), a document describing the environmental implications of a proposed project. The EIS must include (a) a description of the proposed action; (b) the relationship of the proposed action to land use plans, policies, and controls for the affected area; (c) the probable impact of the proposed action on the environment; and (d) any probable adverse environmental effects which cannot be avoided. The EIS must be made available to the President, the Council on Environmental Quality (CEQ), and the public. Title 2 of NEPA created the CEQ, which agency offers general advice and assistance to the President on the preparation of the annual Environmental Quality Report, researches conditions and trends in the quality of the environment, and evaluates various programs and activities of Federal agencies for consistency with NEPA [20:71].

The legal recourse against agencies who fail to follow the provisions of NEPA are limited, especially for private citizens. NEPA is not a long or detailed statute but:

> Despite its relative brevity and generality, however, NEPA is one of only a few statutes that have had a significant effect on the federal decisionmaking process.
>
> In great measure, NEPA's disproportionate impact has resulted from the vast amount of litigation it precipitated. Indeed, NEPA may have led to more lawsuits than all our other environmental laws combined. Consequently, a large body of NEPA case law has been developed, fleshing out and giving specific force to NEPA's general provisions [57:370].

Clean Air Act. The Clean Air Act (42 U.S.C. Section 7401 et seq.) was originally enacted in 1963 but the form it has since taken was shaped in 1970, when this act was put under the control of the EPA, and then again in 1977 when major amendments were made to the act. The original efforts were directed at large industrial concerns that were putting large amounts of dark, obnoxious smelling smoke that was obviously offensive to human

senses. As the problem of air pollution was studied more it was apparent that many of the pollutants most harmful to human health were not nearly so easy to detect. Congressional emphasis all along has been to have the air pollution legislation executed at the state and local level, with federal efforts serving as baseline or minimum standards (21:213-215). The Clean Air Act has had a more pronounced impact on smelters and foundries than on mines and milling operations which have been more affected by other environmental statutes.

National Ambient Air Quality Standards (NAAQS). The EPA is required by section 108 to establish the maximum limits for different pollutants it identifies as being injurious to human health. These limits serve as guidelines for overall air quality in a given area:

> Despite their importance to the scheme of the Clean Air Act, NAAQS are not directly enforceable. They are the controlling force behind the development and implementation of emission limitations and other controls pursuant to other sections of the statute. It is those requirements that are actually enforced against polluters, rather than the NAAQS itself.
>
> The NAAQS establish ceilings for individual pollutant concentrations that should not be exceeded anywhere in the United States. They, therefore, determine the degree of control that will be imposed on existing sources and the restrictions on location of new sources, depending on whether air quality is better of worse than the NAAQS in the particular area where the source is or will be located [21:219].

In other words, rather than having standard emission limits for a particular type of plant or pollutant, the ambient air pollution levels in a particular area may be, in a sense, full, and not open to any other new sources of pollution.

State Implementation Plans (SIPs). In order to assure that the provisions of the Act are carried out at the local level, the states are required to come up with a State Implementation Plan (SIP) for the EPA's approval:

> The key regulatory section of the Act is section 110. It implements the Congressional philosophy that "prevention and control of air pollution at its source is the primary responsibility of state and local governments" and provides a structure under which the states are expected to establish the regulatory framework necessary to achieve the NAAQS. However, it also directs the Environmental Protection Agency to impose the necessary regulations if state governments fail to meet the Act's directives [21:220].

A number of areas in the country have remained under EPA regulation for failure to come up with an acceptable SIP. After being under the SIP for several years many areas did not meet NAAQS standards for one or more pollutant (21:223).

One of the fallouts of the SIP program is that the courts have upheld the "EPA's position that section 110 does not require EPA to engage in a review of technological or economic feasibility when considering SIPs for approval" (21:225). The EPA does in fact consider these factors at other places in the regulatory chain of events.

Clean Water Act. The Clean Water Act of 1977 was an attempt by Congress to get control of all effluents being put into the nation's waterways with the intent to:

> Restore and maintain the chemical, physical, and biological integrity of the Nation's waters . . . The immediate need is still the elimination of discharges into the nation's waters unless legally done pursuant to a permit issued be the EPA [20:27].

The first attempts (prior to 1972 Federal Water Pollution Control Act) at getting a handle on the problem were mostly left to the states without providing real guidelines or minimum effluent standards; the overall program was unsuccessful.

> Although a few states made the water quality approach work, it was clear by 1970 that an effective nationwide approach would require implementation of a permit program based on federal minimum "end-of-pipe" effluent criteria enforceable directly against the discharger [2:266].

The 1972 Act gave the EPA responsibility for coming up with guidelines for effluent limitatons within a certain time period.

> ... EPA was unable to meet many of the deadlines and as a result, in 1976, was sued by several environmental groups. In settling this lawsuit, EPA and the plaintiffs executed a court-approved "Settlement Agreement." This Agreement required EPA to develop a program and adhere to a schedule in promulgating effluent limitations guidelines and pretreatment standards for 65 "priority" pollutants and classes of pollutants, for 21 major industries [13:54599].

National Pollutant Discharge Elimination System (NPDES). The Act requires anyone who discharges any kind of material into a U.S. waterway to do so under a permit. The permit program covers all sources of pollution and all waterways with a very few minor exceptions. The EPA ran the permit program while the states developed their own permit programs that remain under the general purvue of the EPA. The EPA still holds the right to disaprove a permit if it disagrees with a state program's decision (2:272,273).

Effluent Limitations. The EPA has done considerable study in developing its Effluent Limitations Guidelines and Standards for the Ore Mining and Dressing Point Source Category. The main emphasis is to

develop standards for large existing sectors of the mining industry (e.g. copper, lead, zinc, and uranium mining). This study very carefully lays out the types of chemicals present in different types of milling processes for different minerals. Chromium and PGM are not part of the study (as mentioned above) except where platinum is mined as a by product (EPAa, ix). The EPA has come up with a number of effluent limitation requirements for different industries in different situations:

> 1. *Best Practicable Control Technology Currently Available (BPT).* BPT limitations generally based on the average of the best existing performance at plants of various sizes, ages and unit processes within the industry or subcategory. In establishing BPT limitations, we consider the total control of applying the technology in relation to the effluent reduction derived, the age of the equipment and facilities involved, the engineering aspects of the control technologies, process changes and the nonwater-quality environmental impacts . . . We balance the total cost of applying the technology against the effluent reduction.
>
> 2. *Best Available Technology Economically Achievable (BAT).* BAT limitations, in general, represent the best existing performance in the industrial subcategory or category. The Act establishes BAT as the principle national means of controlling the direct discharge of toxic and nonconventional pollutants to navigable waters. In arriving at BAT, the Agency considers the age of the equipment and facilities involved, the process employed, the engineering aspects of the control technologies, process changes, the cost of achieving such effluent reduction and nonwater-quality environmental impacts. The Administrator retains considerable discretion in assigning the weight to be accorded these factors.
>
> 3. *Best Conventional Pollutant Control Technology (BCT)* . . . Conventional pollutants are those defined in Section 304(a)(4) [biological oxygen demanding pollutants . . . total suspended solids . . .] and any additional pollutants defined by the Administrator as "conventional" i.e., oil and grease . . . BCT is not an additional limitation but replaces BAT for the control of

> conventional pollutants . . . the Act requires that BCT limitations be assessed in light of a two part "cost reasonableness" test . . . The second test examines the cost-effectiveness of additional industrial treatment beyond BPT . . . In no case may BCT be less stringent than BPT.
>
> 4. *New Source Performance Standards (NSPS).* NSPS are based on the best availabe demonstrated technology. New plants have the opportunity to install the best and most efficient production processes and wastewater tretment technologies.
>
> 5. *Pretreatment Standards for Existing Sources (PSES), and Pretreatment Standards for New Sources (PSNS).* Pretreatment standards (PSES and PSNS) are designed to control the discharge of pollutants into publically owned treatment works. Pretreatment standards were not proposed for the ore mining and dressing category since no known indirect dischargers exist nor are any known to be planned. Ore mines are located in rural areas, generally far from a POTW [publically owned treatment works]. EPA expects that the cost of pumping mine and mill wastewater to a POTW would be prohibitive in most cases, and on-site treatment is more cost effective in virtually every instance [13:54599-54600].

There have been additions and amendments to the Act that have generally expanded the EPA's prerogatives in regulating and enforcing Congress' will in water pollution issues (e.g. the Water Quality Act in 1987). In civil litigation and regulatory actions the EPA has several premeses it operates under:

> EPA has issued several sets of guidelines concerning the assessment and settlement of civil penalties under the Clean Water Act and other statutes, efforts which have sought to promote uniformity in enforcement and effective deterrence of violations . . . EPA plainly intends to remove any economic benefit that a violation has conferred on a discharger, both in terms of deferring capital investment in control equipment, and in avoiding operation and maintenance costs . . . It is also clear that EPA will treat violations which cause (or threaten) greater harm to the environment or people's health more seriously than those which do not [2:313].

Resource Conservation and Recovery Act (RCRA). The RCRA was put forth to deal with the huge problem this country faces in disposing of solid waste and a subcategory, hazardous waste. Mining wastes, "wastes from the extraction, benefaction, and processing of ores and minerals" (22:66), are exempted from the category of hazardous waste but are dealt with as solid waste. The original Act was enacted in 1976 and has been amended several times since then to expand and further define its influence. Mining activities are only a minute amount of the activities covered by the Act; the major thrust of the Act is to start dealing with municipal waste systems, industrial process wastes, and mostly hazarous waste problems.

> RCRA provided for the creation of a sringent "cradle to grave" manifest system of control over the management of hazarous wastes. RCRA mandated that EPA promulgate criteria for identifying hazardous waste and establish standards to apply to waste generators and transporters, as well as owners or operators of treatment, storage, or disposal facilities for hazardous wastes [20:92].

The EPA, however, did a study for Congress (completed in 1985) on the Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Abestos, Overburden from Uranium Mining, and Oil Shale, which was a look at the solid waste problems encountered by the large sectors of the mining industry. The metal mining covered by the report looks at copper, lead, zinc, silver, and gold. Again, chromium and PGM would be looked at only when it became a current and/or a significant part of the industry. Much of the EPA's work under this Act is to handle past dump sites as well as present and future disposal needs.

Federal Land Policy and Management Act (FLPMA). The FLPMA has to do with land management more than pollution control but in reality it is one of, if not the most powerful legal tool for affecting the quality of the environment.

> The Federal Land Policy and Management Act (FLPMA) (1976) repealed in 1976 a number of public land statutes and instituted a number of new programs including review of all lands managed by the Bureau of Land Management (BLM) for possible designation by Congress as "wilderness" [20:56].

Designation as "wilderness" has huge implications for strategic minerals exploration and mining. This designation is in effect a blanket environmental protection for the said area in most cases.

> The wilderness designation means that those areas may be entered only on foot and that no improvements can be constructed within the area. Some threefourths of America's public lands, many the most richly mineralized areas of the country, now are off-limits to mining . . . For instance, there is legislation pending in the Senate proposed by Alan Cranston (D-CA) that would replace the current California Desert Plan, which was developed over a four-year period with extensive public and industry participation. It allocates approximately 2 million acres of the California desert as wilderness . . . His bill would designate 8.8 million acres as wilderness - four times the current acreage - and, for all practical purposes, would not permit future mineral exploration or mining. Of the 65 mineral commodities known to exist in the California desert, 27 are considered strategic and critical [8:6-7].

Fish and Wildlife Coordination Act. The Fish and Wildlife Coordination Act is not a particularly powerful piece of legislation on the face of it, but its affects can be substantial. It can delay or stop a project:

> Coordination with the Fish and Wildlife Service (FWS) is required on the basis of the methodology existing at the time the project

> and its environmental impact statement, or EIS, were being developed . . . Under the act the U.S. Department of the Interior must review and comment on applications for the NPDES permits under the Clean Water Act. The Fish and Wildlife Service itself has guidelines with respect to review of fish and wildlife aspects of nearly all activities . . . FWCA requires every federal agency to inquire whether any threatened of endangered species may be present in the area of the proposed agency activity before that activity can be taken [20:62].

The Stillwater project required considerable interaction with the Fish and Wildlife Service.

Wilderness Act. The Wilderness Act is more restricted in its application than FLPMA but certainly affects land use issues.

> The Wilderness Act has provided Congressional protection since 1964 for several named wilderness areas and also established a National Wilderness Preservation System for inclusion of lands within the national forests, national parks, and national wilderness refuges. A "wilderness area" is defined as "an area where the earth and its community its community of life are untrammeled by man, where man himself is a visitor and does not remain." A wilderness area is also an area that has outstanding opportunities for solitude or a primitive and unconfined type of recreation." The Secretaries of Agriculture and of the Interior are required to review all land areas within their control to determine whether any land area should be included in the National Wilderness Preservation System.
>
> Mineral entry rights are preserved in the wilderness areas located within national forests administered by the Secretary of Agriculture, but wilderness preservation is paramount over mining activities in terms of protection of human health and environment [20:115-116]

Agencies and Organizations Involved

Environmental Protection Agency. The Environmental Protection Agency (EPA) was made an independent agency in 1970; it was given

responsibilities for environmental issues that were previously taken care of on a fragmented basis by other federal agencies. For instance:

> Air pollution control, solid waste management, radiation control, and the drinking water program were transferred from the Department of Health, Education, and Welfare (now the Department of Health and Human Services). The federal water pollution control program was taken from the Department of the Interior, as was part of a pesticide research program [15:1].

The EPA acquired other areas of responsibility such as pesticde regulation and tolerance levels as well as radiation standards. With the EPA in place, Congress was able to effect more far reaching legislation that would close up many loopholes and get a better handle on pollution control on a national basis. The EPA is responsible for administering some nine different statutes which include from the above discussion: the Clean Air Act, the Clean Water Act, and the Resource Conservation and Recovery Act.

Organizationally the EPA is divided up functionally into divisions that handle water, air and radiation, solid waste, pesticides and toxic substances, and research and development. For administration purposes the country is divided into ten regions that each have a division for water, air, waste management, environmental services, planning, and whatever regional special projects it has (e.g. Region 5 has a Great Lakes National Program Office) (15:1).

United States Department of the Interior. The Department of the Interior had its roots during the 1800s when the U.S. acquired vast territories in the west and needed to have an office to handle the unique problems those territories presented. The main problems in those days were centered around mining, ranching on vast rangeland, and dealing with the Indian nations. The Department has become the manager of the nation's

mineral resources, wildlife resources, national parklands, and Federal Indian reservation lands. There are a number of important agencies under the Department of the Interior; the agencies involved with the problem at hand are discussed below.

Bureau of Mines. The Bureau of Mines is tasked with assessment of the nation's mineral resources as well as researching new methods of mining and processing for ore material. The Bureau conducts field and laboratory studies to ascertain the real and potential strengths and weaknesses of the nation's mineral resources from the in-ground reserves (and potential reserves) to the nation's consumption and import/export status of minerals. They keep statistics of mineral resources mined by different companies at different locations. Much of the data the Bureau collects from private concerns is proprietary and is reflected only in combined values in their reports. The Bureau often does research on special topics (such as domestic chromium resources) at the request of the Executive Branch or Congress.

Bureau of Land Management (BLM). The BLM has a wide portion of the reponsibilities given to the Department of the Interior. Under FLPMA the BLM gained the authority to manage public lands in a consistent way:

> In 1946 . . . BLM became reponsible for managing all the resources on the Nation's public domain lands; however, with more than 2,000 unrelated and often conflicting laws pertaining to the public domain, the agency had no unified legislative authority to manage those lands.
>
> When Congress enacted the Federal Land Policy and Management Act of 1976 (FLPMA), it established a coherent legislative mandate for managing the Public Lands and made BLM a true multiple-use agency . . . Congress declares that . . . the

> public lands be managed in a manner which recognizes the Nation's need for domestic sources of minerals, food, timber, and fiber from the public lands . . . [4:1]

Another area under the purvue of BLM is that of mineral prospecting permits, leases, and patents on claims. The mining resource management includes metallic and nonmetallic minerals, oil and gas, coal, oil shale, geothermal sources, and tar sands (4:8-13).

The "wilderness area" designations and management are part of BLM's task:

> FLPMA provides a legislative mandate for BLM to study the Public Lands for wilderness characteristics and recommend designation of such lands as wilderness areas to the President and Congress. Designated wilderness areas are managed under the authority of the Wilderness Act of 1964 [4:20].

United States Geological Survey (USGS). The USGS is an information gathering organization that has more of an academic science orientation than some of the other agencies of the Department of the Interior. Its approach to a particular project - for instance, a mineral deposit - will be very detailed in its description of the rock types, their origin, the microscopic mineral relationships, the macroscopic formation relationships, etc. The studies that the Survey publishes often do not appear as "mission oriented" as Bureau of Mines publications although the USGS has a number of clearly stated goals summed up as follows:

> The mission of the U.S. Geological Survey is to provide geologic, topographic, and hydrologic information that contributes to the wise management of the Nation's natural resources . . . This information consists of maps, data bases, and descriptions and analyses of the water, energy, and mineral resources, land surface, underlying geologic structure, and the dynamic processes of the Earth [56:2].

The USGS provides an underlying base of data and research for other agencies to use and project from. The academic base they provide will likely be the source from which techniques of exploration are shared among private concerns, and larger relationships are understood - leading to new theories of mineral deposition and discovery of ways to extract minerals from previously uneconomic sources.

American Mining Congress (AMC). The AMC is an organization representing the political interests of the mining industry. Broken out further:

> The AMC . . . members represent: (1) producers of most of America's metals, coal, industrial and agricultural minerals; (2) manufacturers of mining and mineral processing machinery, equipment and supplies; and (3) engineering and consulting firms and financial institutions that serve the mining industry. One specific purpose of the AMC is "To cooperate with government in furthering the national welfare and in developing mining and metallurgy" [3:80].

The AMC president is often invited to testify before congressional committees on matters affecting the mining industry - especially environmental legislation that AMC believes will increase mining costs. A statement by AMC President John Knebel before the Senate Subcommittee on Environmental Protection in August 1987:

> On behalf of the American Mining Congress . . . I ask you to critically evaluate sweeping amendments to the Clean Air Act embodied in the referenced bill . . . These amendments, according to the testimony of EPA Administrator Lee Thomas, could cost more than $30 billion per year, an amount he characterized as "out of proportion to the likely health and environmental benefits" [55:35].

Summary. The various federal agencies often have counterparts at the state level and a pending project may end up dealing with both federal and state agencies for a given location and type of project. A case study follows that will serve as an example of the interaction involved.

Case Study - Stillwater Mining Project

The Stillwater Mining Company (SMC) is a joint venture of three companies (Chevron USA Inc., John-Mansville Corp., and Lac Minerals Ltd.) mining platinum and palladium in southern Montana as described in earlier chapters. The process of getting permission to mine this area has been fairly involved.

Project Proposal. The Stillwater Mining Company proposed to create an underground mine using cut-and-fill stoping (a stope is an underground chamber) and a mill that would process an estimated 1000 tons of ore into 20 tons of concentrate that would be hauled in one truckload to Columbus, Mt. each day. The 980 tons of tailings leftover from the milling process would be used to backfill the mining stopes and whatever tailings are leftover from backfilling (estimated half) would be held in an impoundment area by the mill. The SMC permit request is for 550 acres on National Forest and on private land. The proposal would have left 398 acres relatively undisturbed with the remaining 152 acres being used for the project's various components:

Mine portals, shaft, and yard area

New access road construction

Mill, mine support facilities, and tailings impoundment

Topsoil storage area

Percolation ponds

Misc. (tanks, parking, transmission line, etc.)

[33:Sec II,1-2].

Mining. The actual cut-and-fill mining will entail cutting out the mine framework, then taking tailings (the coarsest sand) from the milling operation in slurry form, adding cement to it, and backfilling the stopes as the miners progress upward - the tailings will solidify and give the miners a platform to stand on. Filling up the stopes will serve to stabilize the walls as miners blast ore from the ceiling of the stope. "Each stope would measure about 200 feet in length, 200 feet in height, and would range in width from 4 feet to 20 feet" (33:Sec II,6).

The total operation will eventually have hundreds of stopes and 70% of them will be backfilled. Some of the mining will be done with shrinkage stoping where "ore is withdrawn from the bottom of the stopes instead of from the sides as in cut-and-fill stoping. The empty stopes would be backfilled with tailings or waste rock, or left empty after the ore is removed . . . (33:Sec II,9). There will be many horizontal shafts and portals as well as two vertical service shafts that will remain unfilled when the project is complete.

Milling. The object of the milling is to break down the ore to where as much waste material as possible is cast aside and the remaining concentration has a much higher percentage of platinum (Pt) and palladium (Pd). There have been a number of studies done by the Bureau of Mines of ways to get the highest concentration of Pt and Pd out of the different kinds of rock that make up the Stillwater ore. Milling is usually a combination of physical alteration and chemical processes that facilitate breaking out the desired mineral from the ore; in this case:

Milling would consist of crushing, grinding, froth flotation, concentrate drying and waste disposal. The company would retrieve the ore from the stockpile, grind it, add water and chemicals to form a slurry of 30 percent solids. This slurry would be subjected to froth flotation, a physical-chemical method of separating and concentrating the metals in finely ground ores . . . The mineral laden froth at the surface of the slurry would be skimmed off, . . . then filtered and dried to form a concentrate of precious metals. The pulp slurry . . . would be piped to the tailings pond for disposal. The froth flotation process would recover over 90 percent of the precious metals in the ore . . . The concentrate would be containerized for shipping [33:Sec II,11].

The Tailings Pond. The tailings pond will be at the same site as the mine and the mill and will consist of an earthen dam built in large part from waste rock from the mine. The height of the dam will be raised in increments to accommodate new levels in the tailing pond. To keep the water in the tailings from seeping into the groundwater, the entire pond basin will be lined with hypalon sheet. The tailings are to be separated out into fine-grain slime, coarse-grain sand, and excess water which will be sent to the tailings pond, back to the mine, and back to the mill, respectively (33:Sec II,13).

Public Reaction. There are a number of factors that have made the project work, the main factor is, perhaps, high grade ore that allowed SMC the economic ability to comply with environmental requirements and still remain a profitable. Other factors are that the sparsely populated public generally supported the project in public forums as have the Stillwater county commissioners. Opposition came from various sources also as reflected by some of the 41 letters of response to the draft Environmental Impact Statement printed in the last chapter of the EIS. Much opposition

from private citizens reflected scepticism and distrust based on earlier mining operations in the same area that have yet to be cleaned up:

> I oppose the proposed platinum and palladium mine . . . The tailings from the previous mining are already an eyesore.
>
> I was around when the Mouat Mine was operating, and I don't think we need that again.
>
> . . . we feel it is important to restore the land so there isn't a mess like there was when we moved up here twelve years ago. We took moving films of the dust from the settling ponds blowing and it would blaze our home's siding and I would find it in our window sills . . . you can imagine how it affected our breathing and lungs.
>
> We are John and Carolynn Mouat. We operate the Stillwater Valley Ranch which adjoins the settling pond land used used by the American Chrome Company to dispose of their tailings during operation of the chrome mines used to produce a Government chrome stockpile from about 1955 to 1965 . . . When the Government contract was terminated in about 1965, the American Chrome Company simply walked away from the project. Buildings were abandoned, water pumps used to flood the tailing pond were turned off and the pond was allowed to dry up. During the next 3 years, Southwest winds of up to 100 MPH blew the dry tailings onto my ranch and onto the adjoining Forest Service. Millions of tons of this fine sand mixed with chrome dust created sand dunes of up to 50 feet in depth on our ranch and the Forest Service.
>
> . . . Nye Creek, which flows through the ranch and empties into the Stillwater River near the ranch house was (and is) filled . . .10 to 15 feet in places, with sand . . . The water flows in the creek near the mountains and disappears into the sand, where it simply disappears. None is flowing into the river.
>
> . . . The sand has infiltrated everything. Windows are sandblasted, the paint is stripped from vehicles . . . Some of us still suffer from respiratory problems caused by the sand.
>
> Anaconda Corporation subsequently acquired the chrome mine property, including the tailing pond . . . Several years were spent in dozing top soil over the sand, creating sprinkling systems,

constructing ponds and planting anti-erosion grasses. The cost to Anaconda, as well as to myself was staggering.

> . . . There are still millions of tons of tailings on our ranch, on the adjoining Forest Service and on the tailing pond. Nye Creek still fills with sand, our windows get blasted and machinery and vehicles still get ruined . . . There is no Anaconda Corporation anymore to help us [Anaconda, one of the original partners in SMC has sold its interests in that area] . . . we must face these problems and pay for the solution ourselves [33:Sec IX,32,21,39,13,14,]

There was a lot of concern about cutting off access to certain roads, stress on the roads, increases in large animal roadkills, and opposition on a number of environmental concerns that were addressed in the final EIS. The comments in support of the project centered around jobs and economic growth that it would provide.

> As a graduate of Absarokee in 1975 I have had a hard time being able to have an occupation in which I could live in this area. However if the mine would be able to go in it would open a greater variety of jobs . . . now there is no future for a younger person in this area . . .
>
> Our community needs a payroll - we need to have a means to keep some of our young people at home - we need to have a means to pay our teachers and continue to operate a good school system. We have had experience with a mine operating in our community and we are not blind to the adverse affects. I feel local residents that have to work for a living share my opinion!
>
> The jobs are badly needed . . . People should . . . realize the number of related jobs that the 223 permanent jobs would create . . . Let's look at the positive side of industry for a change instead of driving them overseas by outrageous wages and environmental demands . . . We need jobs in Montana for those here now and for future generations of this state [33:Sec IX,29,4,2].

Agency Participation. The lead agencies that handled this process were the Montana State Department of State Lands and the U.S. Forest

Service (Department of Agriculture). The reason that the Forest Service has played such an important role in this process is that the actual mine lies within the Beartooth Ranger District of the Custer National Forest. The milling and tailings impoundment area are on private land (owned by SMC) next to the mine. Other agencies involved were:

U.S. Fish and wildlife Service

State Historic Preservation Office

Montana Department of Health and Environmental Sciences

Air Quality Bureau

Water Quality Bureau

Montana Department of Natural Resources and Conservation

Hard Rock Mining Impact Board

Stillwater County

Army Corps of Engineers

Local Conservation District

Table 3 - [33:xi].

Montana State Law. The environmental decisions and permits were handled at the state level and the state requirements were borne out in the EIS. The state requirements are at least as stringent or more stringent than the federal ones. The EPA state office voiced some concerns that the draft EIS had insufficient information; those concerns were addressed in the final EIS (33:Sec IX,34,35). There were a number of substantial actual project changes from the draft to the final EIS that were driven in part by the feedback from the different agency's comments. Several of the hard points in the environmental requirements were mandated by state law that was not in place when the American Chrome Company (mentioned in a letter above) incident took place (33: IX,13).

Montana's Metal Mine Reclamation Act, while recognizing that "it is not practical to extract minerals or explore for minerals . . . without disturbing the surface of subsurface of the earth and without producing waste materials" intends to insure that mining operations restore the earth to a useful form after mining ceases (36:433,434). The Act defines mining operations and what waivers it will allow to its various provisions. Two of the main features are 1) having mining companies post bonds that will insure reclamation of the land if they fail to do so and 2) requiring companies to replace or correct any water supplies they damage (36:445,449).

The Montana Environmental Policy Act lays out the general processes and requirements for obtaining a project permit as well as the EIS process. Part of its premise is to, "assure for all Montanans safe, healthful, productive and, aesthetically and culturally pleasing surroundings", but also to "attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable . . . consequences" (37:2).

The Montana Department of State Lands has much more procedural detail in their Administrative Rules of Montana subchapter on Rules Implementing the Montana Environmental Policy Act. The terms in MEPA are carefully defined and the EIS procedures are laid out step by step.

The way the EPA system is set up, as long as the Montana State plans for permits and EISs have been approved by EPA (they have), the company making the request has only to deal with the state approval processes. In this case the U.S. Forest Service and the U.S. Fish and Wildlife Service were involved; both of these agencies, however, kept their dealings within the context of the state process. The EPA reviews the work done in the state

process and maintains the right to disapprove it if it feels it will not adequately comply with the federal standards.

EIS Environmental Considerations. The Stillwater EIS deals with the total impact of the mining operation on the locai area to include:

Geology - structural, surficial

Hydrology - surface and ground water

Soils - farmland, erosion

Vegetation

Aquatic Ecology

Fisheries

Wildlife - big game, birds

Threatened and Endangered Species

Climate - precipitation, temperature, winds

Air quality

Employment and Income

Sociology - local area

Community Services - schools, medical, law enforcement, fire protection

Fiscal Conditions - schools, tax base

Land use - trends, range condition

Transportation - bridges, federal aid for roads

Recreation - National Forest, Community

Cultural Resources

Aesthetics - visual, noise

Table 4 - [33:xii-xiv].

In a record of decision to approve the project, the Supervisor for the Custer National Forest, David Filius layed out the preferred alternatives

selected for mine operation and how they would best answer the concerns brought out in the EIS process by the various agencies and citizens:

1. <u>Water Quality and Quantity.</u> The project is expected to have no effect on water quality or quantity. However, to assure that the project does not have any adverse affects, SMC will prepare for DSL [Department of State Lands] and USFS [U.S. Forest Service] a water quality compliance monitoring plan (Ref: EIS Chapter I-14 & IV-8). The plan will specify monitoring sites, sampling frequency, parameters, sampling and analytical methods . . . used to analyze ground and surface water potentially affected by the project . . . SMC will prepare . . . a spring flow monitoring program to . . . ascertain the effects of mine development on nearby springs.

2. <u>Community Services.</u> SMC and Stillwater County have prepared . . . an impact plan that describes expected impacts to and proposed payments for community services provided by the County, Absarokee, Columbus, school districts, and special districts . . .The company is responsible for paying all increased net operating and capital costs of local government due to the hard rock development (90-6-307(2), MCA). The impact plan identifies a total tax prepayment of 2.3 million . . . to cover increased costs of providing community services and facilities due to mine and mill employees migrating into the area.

3. <u>Reclamation.</u> The reclamation measures presented in the operating should result in adequate reclamation. A bond will be held by the State Department of Lands until reclamation is deemed successful by DSL and USFS . . . Success of the reclamation will be judged by comparing the extent and condition of the vegetation on the project area with that observed on adjacent undisturbed areas.

4. <u>Fisheries and Aquatic Ecology.</u> The project should not directly affect fish habitat or aquatic ecology (Ref: EIS page IV-11). Indirect effects such as increased fishing pressure will occur . . . SMC will be required to periodically survey employees as to their recreation usage patterns in the Stillwater River basin . . .

Also, to assure that degradation of the fish habitat below the mine does not occur, sampling of substrate . . . in the Stillwater River below the mine will be required . . .

5. Recreation. The addition of several hundred users of National Forest System [NFS] lands to the current use of the area will not have a major impact. There is a potential for conflict between NFS recreation travelers and mine traffic, particularly at shift changes . . . SMC will implement an employee busing or van/car pooling program with a target of reducing traffic on FAS 419 . . .

6. Air Quality. Particulate emissions from the mining and milling operations would be minor (Ref: EIS page IV-34). The tailing pond would be covered with water . . .Some windblown dust is anticipated from the dam face. The conifer shelterbelt to be planted at the base of the toe dam . . . will help reduce adverse effects of this condition.

7. Wildlife. Activity of the project would disrupt bighorns and a small portion of the winter range used by the bighorn sheep would be destroyedor rendered unuseable during the life of the project . . . the bighorn sheep population has shown a dramatic downward trend since the initiation of mining activity in recent years . . . SMC will prepare for DSL and USFS approval a plan to monitor the affects of mine development and operation on the Stillwater bighorn sheep herd . . . SMC will carry out an employee education program about the adverse affects of disturbance on bighorn sheep and discourage nonessential entry into bighorn range during winter months.

8. Wilderness. There will be no direct impacts on the Absaroka-Beartooth (A/B) Wilderness (Ref: EIF page IV-57). An increase of five to seven percent to the population of Stillwater County will have its additive affect on the current users of the A/B Wilderness. This increase can be accomodated within the estimated biological carrying capacity of the area.

9. Lifestyle. The project would not cause rapid social change in the county, but will likely have some impact in the immediate

area. The population increase due to mining will not significantly alter the existing political structure of the county.

10. Land Uses. The project will not have a significant impact on the agricultural production in Stillwater County. Further subdivision of rangeland could occur for housing or commercial services (Ref: EIS page IV-51).

11. Aesthetic Values. The mine, mill, and associated facilities will change the visual quality of the site. The current visual quality objective of retention set forth in the Beartooth Face Land Management Plan could not be met. The company will be required to reduce the visibility of the operation by planting a mixed conifer shelterbelt in two places . . . Natural-color poles and insulators would be used to reduce the visual effects of the 13-kilovolt 'ine between the mill substation and the Mountain View shaft site (Ref: EIS pages I-16 & IV-62).

12. Mining Methods. Between the draft and final, the company revised its operating plan to specify a high percentage of cut-and-fill stoping. This change came as a result of refined underground information on the nature of the ore body (Ref EIS Chapter 2).

13. Subsidence. To prevent surface subsidence, the company would leave a 20- to 50-foot solid rock roof (known as athe crown pillar) over the entire mine cavity . . . the ceiling would be rock bolted to prevent spalling (disintegration by chipping and flaking) . . . Most of the stopes will be mined using cut-and-fill methods. This means the stopes will be backfilled with mill tailings, which will minimize or eliminate susidence (Ref: EIS Chapter 2).

14. Alternatives. In the draft EIS six alternatives to the company production system were explored. Due to changes in the SMC's operating plan, only three development alternatives were examined in the final EIS. The three tailing pond sites were selected from 18 potential sites . . .

15. Power. A preferred power supply alternative cannot be reliably icentified until the DNRC completes a thorough analysis of

present and future load demands of the Stillwater area, the service capacities of alternatives, the environmental impacts, and the costs . . .

16. Transportation. Four roads are affected by mine related travel . . . Traffic increases would be significant between Nye and Fishtail . . . Stillwater Mining Company has agreed in the hard-rock mining impact plan to fund 20 percent (up to $1,460,000) of the cost of reconstructing FAS 419 (including bridges) if additional Federal, State or other funding becomes available prior to 1990 . . .

17. Income. The operation will add considerable income to the local economy. Average annual salaries would be approximately $23,000. This is higher than most people in the county currently earn [December 1985]. The effect of these somewhat higher average salaries on local cost of living is unknown.

18. Employment. The project will employ approximately 220 employees once full operational mode is reached. Of these, 40 percent [88] are expected to be hired locally . . . Local outfitting business should not be affected.

19. Taxes. The Stillwater project would add $3,700,000 to the Stillwater County taxable valuation . . . An indirect increase in taxable value of approximately $343,000 would result from residental and commercial property built by people migrating into this area . . . Increases in taxable value would occur gradually . . . reaching a stable level during the project's sixth year.

Three percent of the gross proceeds of metal mines are subject to property tax . . . At full production, Stillwater Mining Company would contribute $696,382 in gross proceeds to the taxable valuation . . .of Stillwater County at current metal prices . . .

20. Mine Shutdown. Permanent closure of the project, whether after the scheduled 30 years or earlier, would shrink the employment base to what it would have been if the mine had never existed . . . If the closure were short, less than 6 months, only mine workers themslves would be affected . . . During closure

the company would be required to stabilize the tailing pond and any other areas subject to erosion.

21. Milling Chemicals. The general toxicity of the chemicals to be used in the milling process is low (Ref: EIS page VI-12, Appendix C). The impoundment liner will prevent leakage into the groundwater. Even if some leakage occurs, the amount of tailing water would be very small in comparison to the amount of groundwater flowing through the valley. This dilution will render any leakage virtually undetectable downstream from the tailings impoundment.

22. Water Use. The operation will use about 350 gallons of water per minute. Most would come from underground workings and recycling of the mill discharge . . . Monitoring of mine and mill use and the effect on certain springs in the valley will be required. Should it be determined that the company has adversely affected an offsite water supply, they would be required by State law to take remedial action or replace the supply.

23. Natural Hazards. The mine site lies within or close to two landslides. Studies have shown these to be stable and no problems are anticipated. Earthquakes could speed deterioration of the crown pillars and cause internal rock fall.

24. Other Effects. The area in which the project lies could, through time, be subjected to: a) future mineral development, i.e., continued development of platinum/palladium after the initial 30-year operating period, and/or other locatable minerals; b) subdivision; c) increasing numbers of people for recreation and leisure pursuits; and d) a small increase in timber harvest . . .

. . . Deposits of chrome and nickel also occur in this area. At today's metal prices, these are not economical to mine, and plans to produce chromium or nickel . . . are unknown.

People will continue to move into the area regardless of the availability of steady employment activities . . . ranching as an activity will decrease. Mule deer populations will likely drop and whitetail deer, responding to changes in habitat along river bottoms, will increase . . . [34:5-11].

The Stillwater project is currently well under way as noted in the previous chapters. SMC is meeting its obligations under the agreements made pursuant to receiving a permit to operate.

Commentary

The results of the interviews indicated that the focus of EPA's air pollution programs for metal mining are on the large lead and copper smelters which are a significant source of pollution. Some of the pollution problems (especially lead smelters) do not have technological fixes at any price that will bring them within EPA standards. So, attention to chromium and PGM ventures will be dealt with as they come about. The EPA water standards would require a permit for a mining operation the same as any other industrial project. The interviewees also indicated that the solid waste requirements have not yet been applied to metals mining at the federal level, but studies are being done in that area.

Summary

Over the past 20 years Congress has put together a number of sweeping environmental statutes that have evolved into a package of powerful tools to implement change on a national scale. The EPA has spent many manyears developing standards for the environmental parameters within its purvue. The implementation of Congress' programs at the state level has worked better in some places than others and the ramifications of these statutes have been hammered out in the courts to a large extent.

The Stillwater project is an example of a private mining concern working through the system, coming out meeting the environmental requirements, and still functioning in a manner that allows them to meet

their goals. The environmental statutes are workable, at least in this case. Again, the driving factor for success is probably having high-grade ore that is competetive in the market place. The Stillwater project is a good example of the applicability of the environmental laws because, as a new project it is not eligible for any time waivers like existing projects are; conversely, it had the advantage of using the best available technology and design from the beginning.

V. Summary, Conclusions, and Recommendations

Summary

Chapter 1. The problem of U.S. import dependency for a number of critical metallic minerals was introduced in chapter one and focused down to two of the more important metals the U.S. imports: chromium and platinum-group metals (PGM). These metals are important to defense industry production and commercial industry as well. There are several factors that influence the lack of domestic production of chromium and PGM: resource availability, international competition, and federal environmental programs. The environmental programs are sweeping and they are not going away. The piece of the overall problem to be looked at was identifying domestic resources of chromium and PGM and the effects of the federal environmental statutes on the potential development of those resources. The study was exploratory in nature and was to be looked at with an extensive literature review and with unstructured interviews of people in agencies and organizations that are directly involved with the problem. The results of the interviews are in the commentary sections of chapters 2, 3, and 4.

Chapter 2. In chapter two groundwork was laid for the rest of the study by defining and desribing a number of aspects for both the chromium and the PGM issues. Chromium was described in terms of its mineral form, industrial form, and uses in industry. Mined as the mineral chromite, it is converted for industrial use (depending on quality and type of impurities) into either metallurgical, refactory, or chemical grade chromium. It was then placed in the context of the international market for chromium, the

geographical distribution of production and reserves, and the main features of geological deposition. The U.S.S.R. and South Africa produce a majority of the world supply of chromite and the rest of the production is divided out among a number of other countries. The massive production is coming from stratiform deposits while podiform deposits, that supplied so much of the world supply of chromium in the past, are being rapidly depleted. Platinum-group metals (PGM) were then described as critical in fossil fuel production, and in electronic and electrical components. The international market is virtually dominated by South Africa and the U.S.S.R. dividing evenly 94% of world PGM production in 1987. The geological deposition of PGM is often similar to that of chromite.

The last section of the chapter looked at general U.S. government policy towards the mining industry in terms of pollution control and land use issues. In the mainstream, the metal mining industry has experienced a severe decline in the 1980's. The decline is due, in part, to being a high-risk, capital intensive industry with very restricted land access in the high probability areas for minerals, as well as expensive environmental regulations to deal with.

Chapter 3. In chapter three the known domestic deposits of both chromium and PGM were described. The CONUS deposits of chromium and PGM are more thoroughly understood than those in Alaska. The Stillwater Complex in Montana is the biggest U.S. deposit of both minerals. There are considerable chromite deposits in California and some less important ones in Oregon, Washington, and Wyoming. The east coast deposits are relatively insignificant. There are PGM deposits of some importance in Minnesota; there is a small amount of PGM produced in the southwest as byproducts of copper mining. There are large resources of both minerals in Alaska. The

selection of the deposits were made generally without reference to current market prices, so most of the deposits mentioned are currently uneconomical to develop - especially chromium deposits in the CONUS. The criteria for selecting deposits was based more on their value in a hypothetical future national emergency situation; i.e. in general, if market price were not a significant factor, would the deposit be big enough by size and/or concentration to spend the time developing it? The deposits were broken out by states with Alaska being a separate category for both minerals. This chapter also dealt with the extent to which many of the deposits are known or understood - especially in Alaska where the deposits tend to be much more remote and less well explored than those in the lower 48 states.

Chapter 4. In this chapter the major pieces of federal environmental legislation affecting the mining industry in this country were reviewed and the agencies and organizations that carry out the legislation were described. The body of environmental legislation has changed over the past twenty years into a large-scale attempt to deal with a serious problem. Congress has consolidated disjointed groups of laws onto sweeping acts, and sideline environmental functions into primary organizations. The main environmental statutes in this problem area are the:

National Environmental Policy Act (NEPA)

Clean Air Act

Clean Water Act

Resource Conservation and Recovery Act (RCRA)

Federal Land Policy and Management Act (FLPMA)

Fish and Wildlife Coordination Act

Wilderness Act

The NEPA requires federal agencies to prepare an environmental impact statement (EIS) for any project that will affect the environment in any way, while the Clean Air Act is aimed at obtaining National Ambient Air Quality Standards and involving local government in this process through a state implementation plan (SIP) program. The Clean Water Act is an attempt to control sources of water pollution by means of a permit system called the National Pollutant Discharge Elimination System and developing standards for industrial technology that affects effluent discharge. The RCRA deals with solid and hazardous waste disposal and does not yet affect the mining industry at the federal level, but studies are being done on the effects of mining solid waste. The FLPMA affects the access that mining concerns have to federal lands, while the Wilderness Act is a way for Congress to set aside areas of federal land to remain primitive and undeveloped. Finally the Fish and Wildlife Coordination Act requires that the Fish and Wildlife Service be consulted on any project where endangered species may be affected. Because chromium mining is non-existant and PGM mining is statistically almost insignificant the environmental guidelines do not address them specifically.

The agencies and organizations involved in this process are the:

Environmental Protection Agency (EPA)

Bureau of Mines

Bureau of Land Management (BLM)

U.S. Geological Survey (USGS)

American Mining Congress (AMC)

The EPA administers the Clean Air, Clean Water, and Resource Conservation and Recovery Acts that affect the mining industry. The Bureau of Mines devolops mining and ore processing techniques, compiles and keeps statistics on the mining industry, and tracks mineral imports and

exports. The BLM has overall management of the land access issues. The USGS does much of the underlying academic fieldwork for the Bureau of Mines' statistical studies. Finally, the AMC represents the mining industry's interests in Congress and other political forums. In order to see how these environmental laws play themselves out through the various agencies, a case study of the Stillwater mining project was done in the concluding section of the chapter.

Conclusions

Availability of Domestic Resources. There are considerable domestic resources of chromium and PGM. The present reality of most of those resources being subeconomic at current price levels seems to dominate the thinking of most of the individuals interviewed and authors of literature on strategic minerals. The definitions of reserves and resources are important here; reserves are currently economical deposits while resources are deposits that are in ground and could be potentially economical at some time in the future. The amount of reserves changes with the market price but resources represents what is actually there regardless of price. Import dependency on a year to year basis has more to do with reserves than resources, i.e. industry will not buy domestic minerals if imported minerals are much cheaper. Domestic chromium and PGM prices generally cannot compete with import prices.

The part of the equation that makes strategic minerals strategic is that defense and commercial industry needs them and has to import most of their requirements for them. The vulnerability issue is that during a national emergency, supplies of those materials could be cut off. There are two basic scenarios of concern here: 1) A peacetime scenario where

economic pressure is being applied to the U.S. by attempts to either block imports of strategic minerals or market manipulation that keeps international prices extraordinarily high or, 2) a wartime situation where shipping lanes are physically blocked and the U.S. is unable to obtain the materials neccessary to sustain a war effort. In the first scenario, the U.S. would have time to act and make some economic and political moves and would have the formerly subeconomic deposits as a last resort option. During a war scenario, though, a number of extraordinary things would likely take place in regard to strategic minerals: government reallocation of resources between defense and commercial industry, rise in market prices for strategic minerals, use of the National Defense Stockpile and large recycling efforts. Without regard to current price, the chromium and PGM necessary to see the U.S. through a supply cut-off of any conceivable duration are present in the ground. Whether they could be accessed in a timely fashion, given the current state of Alaskan infrastructure and domestic smelting facilities, is unknown. The nature of the resources presently understood is such that the U.S. will likely never be self sufficient in chromium or PGM given present free market/trade conditions (i.e. peacetime) and current industrial/technological configurations (demand levels). The U.S. will continue to be involved in the global market but has resources available to get chromium and PGM in a national emergency.

Field Studies. The nature and extent of many deposits is not clearly known and are often estimated in the field conservatively to what the geologist can substantiate, even though he may think that more could be demonstrated by more thorough testing techniques. In the case of Alaska, for chromium, in order to complete the study with the resources and time available, the Bureau of Mines' study on the Chugach trend set some very

tight restrictions on the deposits they would even consider, e.g. "Access route must not exceed 10 miles to tidewater or existing transportation systems" (16:7). Several of the deposits surveyed in Alaska were accessable by helicopter only. It is very likely that there are deposits that are undiscovered in Alaska and even in the CONUS; there are vast areas of wilderness that have been subjected to little or no mineral exploration with advanced techniques.

The Environmental Legislation. The federal body of environmental legislation has been put in place to meet some real problems in this society: 1) industry and government now has to consider the expense of clean up when planning a project, 2) air, waterways, ground water, and fish and wildlife are in the public domain and must be used in a manner prescribed by the public (through the law). Historically, a private land owner could do whatever he wished with his land. The law has come to recognize the interelationships in natural processes and, in simple terms, takes into account that pollutants dumped into a stream on one person's property flows down to the next person's part of the stream.

As the effects of various kinds of pollution are better understood, legislation is being passed to address different problems within the purvue of the major legislative acts. As the EPA has set out to enact the various laws it has often given grace periods for certain industries to acquire proper operating equipment that would allow them to operate within the standards set by the EPA. The EPA has also, most often, taken into account (e.g. in effluent limitations) the cost to the industry and the technologies available to that industry.

Effects on the Mining Industry. Mining is a very capital intensive industry and the environmental requirements can add significant up-front

cost to a mining operation as seen at the Stillwater project. That makes it very important for a mining company to be sure of the grade and amount of the ore being dealt with. By the time the mine starts seeing a return on its investment it will likely have been several years past when exploration was started - that fact alone will discourage mining operations that appear to be only nominally profitable. High risk also discourages investing in exploration (which is expensive).

The environmental laws have made mining companies responsible for cleaning up their own mess. In this system of government, public opinion can count, as seen in the environmental impact statement (EIS) process. Running a clean, responsible operation can pay off in the long term, such as the Stillwater Mining Company (SMC) wanting to mine more of the complex later on; if SMC makes a mess of their current operation or drags their feet about complying with the EIS, they would have to get the same people to approve another permit.

Recommendations

Exploration. The unknown factor in domestic resources of chromium and PGM is large enough to warrant additional exploration activity. The major portions of relatively unexplored territory are mountainous areas owned by the government. Private industry is not funding exploration for many areas where they there is no realistic hope of obtaining permits to operate (or in some cases to do exploration). It is important for the government to know what resources are available within its borders - especially in this case where those materials are normally imported. An investment in a comprehensive mineral exploration program by the government would be a relatively inexpensive way to answer some

important national security questions rather than just guess at them. It might well turn up new resources of chromium and PGM as well as other minerals.

Environmental Concerns

In the political arena the wilderness area designation has probably been sought for some areas by groups that would like mineral exploration not to occur in those areas for fear of a private mining operation being set up and changing unique primitive wilderness. Those fears are probably legitimate for two reasons: 1) there is a growing pressure on the National Parks System and other public lands from the expanding human population that is having less than desireable results on the environment and wildlife, and 2) if a major natural resource discovery is made there will likely be incessant pressure from private concerns to develop it as soon as they can. In an abstract sense, there is a value in having subeconomic deposits - they are of no present interest to mining concerns but they exist and could be developed if the country needed them.

Mineral resources are useful if they can be mined out and processed when they are needed. In order to be in position to develop subeconomic resources (in an emergency) the government would be much better off if the ground work for the projects were completed to the extent possible; the operations could then be done within the scope of existing law instead of resorting to emergency measures that could be contested and subsequently hung up in the courts. This would partly involve doing the skeleton studies for EISs and updating them periodically. It might mean legislating assurances that the resources would not be developed except in a national emergency - defined and set up with cross-checks to satisfy the legitimate worries of environmental groups.

The recommendations of this study lend little support for the current metal mining industry situation; even though it will undoubtedly be critical in a national war-time scenario. Like the steel, auto, and cast-forging industries, the metal mining industry has to survive on its own merits during free market, peace-time conditions. In the U.S. system of economics it is unlikely that major sectors of heavy industry will be subsidized by the government with one hand so that the defense industry can get cheap domestic materials with the other hand. This may force the government to spend money on things to cover contingency plans that they had formerly counted on private industry for.

Recommendations for Future Research

Some questions that extend from this study might include:

1) What are the developments in technology that would allow a mining concern to more efficiently comply with federal environmental statutes?

2) How might the government's agencies provide incentives for private concerns to invest in exploration and development?

3) What are the actual resources of other strategic minerals, and how is the government approaching the need for them?

4) How long would the National Defense Stockpile provide the neccessary levels of materials to industry while subeconomic resource development was beginning?

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[redacted]

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFIT/GCM/LSP/88S-4	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: School of Systems and Logistics; 6b. OFFICE SYMBOL (If applicable): AFIT/LSY	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Air Force Institute of Technology, Wright-Patterson AFB OH 45433-6583	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

See Box 19

12. PERSONAL AUTHOR(S)
Leon D. Engman, B.S., Capt, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
MS Thesis	FROM ____ TO ____	1988 September	101

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
08	09	07

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Strategic Minerals, Chromium, Platinum-Group Minerals, Strategic Metals Mining

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: Domestic Production Issues in Chromium and Platinum-Group Metals

Thesis Chairman: Dr. William Pursch
Professor of Contracting Management

Approved for public release IAW AFR 190-1.

WILLIAM A. MAUER 17 Oct 88
Associate Dean
School of Systems and Logistics
Air Force Institute of Technology (AU)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr. William Pursch	22b. TELEPHONE (Include Area Code): (513) 255-3944; 22c. OFFICE SYMBOL: AFIT/LSP

DD Form 1473, JUN 86 Previous editions are obsolete.

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This study looked at the issues in domestic production of Chromium and Platinum-Group Minerals. It first identified all the known resources of Chromium and Platinum-Minerals in the U.S. and the extent to which the deposits are understood. Then the federal environmental statutes affecting the mining and exploration of these two minerals were described. The relationship between the environmental statutes and the mining industry varies because the statutes are implemented at the state and local level. A case study of the Stillwater mining project served to demonstrate how a proposed project can work through the existing laws and regulations.

There are considerable resources of Chromium and Platinum-Group Minerals in the U.S. that are mostly subeconomic in free-market conditions, but would be viable sources of strategic minerals in a national emergency. From the production side, the federal environmental programs have been put in place for very legitimate reasons but have added considerable expense to mining operations. If an economic grade of ore can be demonstrated, though, a given mining project proposal can be worked through the environmental laws and regulations and still compete in the market place as demonstrated by the Stillwater project.